CHANGES IN VEGETATION FOLLOWING SITE PREPARATION AND UNDERSTORY RESTORATION WITH THE FOREST HERBICIDE HEXAZINONE

By

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To Sandra, Ashley and Matt

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Abstract of Dissertation Presented to the Graduate School of the University of Florida in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy

CHANGES IN VEGETATION FOLLOWING SITE PREPARATION AND UNDERSTORY RESTORATION WITH THE FOREST HERBICIDE HEXAZINONE

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Changes in forest plant communities following applications of hexazinone were evaluated with three studies: i) rate-response experiments on 3 one-year-old clearcuts, each representing a point along a generalized edaphic gradient (xeric sandhill, mesic flatwoods, and hydric hammock); ii) comparisons of hexazinone and mechanically site prepared (shear and windrow) loblolly pine (Pinus taeda) plantations established 7 years earlier on hydric hammock sites; and iii) rate-response experiments for understory restoration of a successionally advanced, xeric sandhill site.

Cover by woody species decreased with increasing hexazinone rates (0.0, 1.7, 3.4, and 6.8 kg/ha) on all sites along the edaphic gradient. Herbaceous vegetation recovered from first-season reductions to levels that did not vary

with treatment (xeric sandhills and mesic flatwoods) or increased with increasing hexazinone rates (hydric hammock). Hexazinone tolerance by Gelsemium sempervirens and Vaccinium spp. on the xeric sandhill, and Ilex glabra and G. sempervirens on the mesic flatwoods influenced diversity response by woody and herbaceous vegetation. With increasing rates, herbaceous diversity decreased on the xeric sandhill, did not vary on the mesic flatwoods, and increased on the hydric hammock.

When compared with hexazinone applications (3.4 kg/ha), mechanical site preparations resulted in greater numbers of woody species. While mechanically-treated stands had higher alpha diversity, hexazinone treated stands exhibited greater beta diversity. On mechanically-treated stands, beta diversity and distributions of some species were related to windrow proximity.

Hexazinone (0.42, 0.84, and 1.68 kg/ha) selectively controlled oaks (Quercus spp.) <14 cm dbh on the successionally-advanced xeric sandhill, and prompted release of wiregrass (Aristida stricta). This suggests that hexazinone may have use for restoration of longleaf pine (Pinus palustris) - wiregrass ecosystems.

Plant community responses to hexazinone are functions of application rate, edaphic factors, adaptive strategies of resident species, and the presence-absence of hexazinone tolerant species.

CHAPTER 1
GENERAL INTRODUCTION

Prediction of forest productivity in response to vegetation management strategies, e.g., herbicide applications, is restricted by a lack of knowledge concerning plant response to changing environmental conditions (Radosevich and Osteryoung 1987). Adding to these uncertainties are mandates for the maintenance of biological diversity [National Forest Management Protection Act; Federal Register 44(181), 219.13(6)], and restoration and management of critical wildlife habitats [Endangered Species Act of 1973 (16 U.S.C. 1531 et seq.)]. Furthermore, public involvement in vegetation management policy formation has necessitated consideration of practically all non-timber impacts of herbicide use (USDA 1989). These additional management constraints increase the uncertainty of herbicide use and requires assessment of the impacts and uses of these compounds from different perspectives.

Hexazinone (3-cyclohexyl-6-(dimethylamino)-1-methyl-1,3,5-triazine-2,4(1H,3H)-dione) is a selective herbicide registered for site preparation, release, and herbaceous weed control for pine (Pinus spp.) production in the southern United States (Nelson and Cantrell 1991). Research on hexazinone for forestry uses has been largely

concentrated on efficacy trials for control of woody or herbaceous weeds that compete with pines, and thereby affect their survival and growth. Little emphasis has been placed upon vegetation dynamics other than from a weed control perspective. On a few sites, basic plant community responses to hexazinone have been documented. These have tended to be for low-rate applications on old-field pine plantations (Blake et al. 1987), or only for woody vegetation following release treatments (approximately 50% lower than rates used for site preparation) (Zutter and Zedaker 1988).

At present, generalizations concerning the influence of hexazinone site preparation on plant community dynamics of sites in the lower Coastal Plain are based on incomplete data. Documentation of plant community responses to hexazinone on a variety of sites in the lower Coastal Plain would allow for improved predictive abilities. Furthermore, comparisons with alternative treatments would allow decisions to be made concerning the relative merits of different site preparation techniques. Finally, weed control strategies developed for pine plantations might be adapted to control vegetation in natural pine systems that are not managed for fiber production.

Two basic strategies for detecting response patterns in multi-species communities are: i) experiments where treatment parameters are varied in a factorial fashion and individual plant responses are measured under a variety of

species mixes; and ii) descriptions of the observed patterns in the abundance of species (i.e., richness, diversity, dominance, and spatial distribution) (May 1981). This dissertation reports on a set of studies that incorporates elements of both of May's strategies. Existing plant communities were used, so complete sensitivity analyses for all plant species mixes under a variety of conditions (May's first strategy) were not practical. The explicit purpose of conducting these studies was to enhance predictability associated with hexazinone use. The geographical region of interest was the lower Coastal Plain of north-central Florida.

Characteristics of Hexazinone

An understanding of the impacts of hexazinone on forest plant communities would be incomplete without a basic knowledge of the herbicide. Questions posed about forest herbicide characteristics routinely pertain to environmental fate and mode of action. Hexazinone is a triazine herbicide that is highly soluble in water (33000 mg/L at 25 C), and is potentially very mobile in subsurface solution (Neary et al. 1983, Bouchard et al. 1985). Following applications of 1.68 kg a.i./ha, off-site movement of hexazinone has been observed to be minimal and of low toxicity risk to adjacent aquatic ecosystems (Neary et al. 1983). Following the same treatment, invertebrates experienced no major changes in community composition (Mayack et al. 1982). Following applications of 2.00 kg a.i./ha on sandy loam sites in

Arkansas, off-site movement was 2.0-3.0%, and <0.10% of that applied was returned to the forest floor upon oak defoliation (Bouchard et al. 1985).

Persistence of hexazinone in forest soils is relatively short-lived. The half-life of hexazinone in silt loam soils in Delaware, Illinois and Mississippi has been reported as 1, 2 and 6 months, respectively (Rhodes 1980). In Alabama, half-lives were 4-6 weeks in clay soil, and <4 weeks in loamy sand (Sung et al. 1981).

Although foliar penetration of triazine herbicides does occur (and this can be enhanced by adjuvents) (Esser et al. 1975), primary uptake of hexazinone is from soil solution by roots (Ashton and Crafts 1973). Soil adsorption of hexazinone is amplified by increasing clay and organic matter content (Nelson et al. 1981), such that root uptake and subsequent herbicidal activity are decreased (Minogue et al. 1988).

Following absorption, hexazinone is distributed through the transpirational stream to its site of action in the chloroplasts (Ashton and Crafts 1973). There, the compound binds to a specific protein and inhibits its ability to mediate electron transport -- the Hill reaction (Van Rensen 1989). This results in a build-up of triplet state chlorophyll that generates singlet oxygen (Dodge 1982). Singlet oxygen peroxidizes cell membrane lipids and the affected plant dies from oxidative stress (Balke 1987, Bartels 1987).

Some woody species gain tolerance to hexazinone by having greater abilities to metabolize the compound before it reaches the site of action [e.g., loblolly pine (Pinus taeda) when compared with Quercus spp. (McNeil et al. 1984), and Pyrus melanocarpa when compared to Rubus hispidus (Jensen and Kimball 1990)], while others gain tolerance with reduced translocation [e.g., Vaccinium spp. when compared with Solidago fistulosa (Baron and Manaco 1986) and Juniperus virginiana when compared with loblolly pine (McNeil et al. 1984)].

Dissertation Format

This dissertation incorporates results from three separate studies, each concentrating on a different aspect of plant community response to hexazinone. The opening chapter (Chapter 2) focuses on responses of individual species and plant communities to hexazinone site preparation at different application rates on three contrasting sites (xeric, mesic, and hydric). Response modelling was conducted for dominant plant taxa, and an overall null hypothesis was tested that short-term rate-responses of plant species diversity and species-abundance distributions are qualitatively the same for all sites in the region.

In Chapter 3, relative impacts of two site preparation alternatives on hydric hammock vegetation were compared. Hexazinone site preparation was contrasted with a mechanical treatment (shearing and windrowing). Two replicates of each treatment were evaluated for testing the null hypothesis

that abundance of individual species as measured by foliar cover, numbers of species, and spatial organization of those species were the same following both treatments. Results of these comparisons were used to evaluate the relative impacts of these alternatives on the composition of plant communities and wildlife habitats within the hydric hammock ecosystem.

Chapter 4 explores the potential uses of hexazinone as a management tool for understory restoration of longleaf pine (P. palustris) - wiregrass (Aristida stricta) communities on xeric sandhill sites. This endangered ecosystem (Means and Grow 1985) occupies approximately 15% of its original 28 million ha in the southeastern U.S. (Croker 1979). On a large proportion of those sites where it currently exists, fire suppression has allowed for encroachment of scrub oak midstories, resulting in suppressed herbaceous ground cover. Development of methods for facilitating the reintroduction of summer ground-fires to these sites has been identified as a restoration priority (Noss 1988). The object of the study was to test hexazinone rates that would release relictual wiregrass from scrub oak competition with a minimum of impacts on other plant species.

The concluding chapter is a synthesis and summary. Results of all three studies are used to predict some long-term impacts of hexazinone use.

CHAPTER 2
VASCULAR PLANT COMMUNITY DYNAMICS FOLLOWING HEXAZINONE SITE PREPARATION IN THE LOWER COASTAL PLAIN

Introduction

Establishment of pine (*Pinus* spp.) plantations in the lower Coastal Plain has traditionally been accomplished with intensive mechanical disturbances (Worst 1964, McMinn 1969) involving methods that often result in long-term degradation of site productivity (Morris et al. 1983, Swindel et al. 1986). Herbicide use offers an alternative that may be more economical and cause less soil disturbance and nutrient displacement than mechanical means. Chemical site preparation has been shown to provide effective competition control and is, therefore, replacing intensive mechanical methods in many forest types in the southeastern U.S. (Walstad and Kuch 1987).

Hexazinone is one of nine herbicides currently registered for forest site preparation in the southeastern U.S. Hexazinone is available commercially as Velpar ULW™, Velpar L™ (E.I. Du Pont De Nemours & Co.), and Pronone 10G™ (Pro-Serve, Inc.). Manufacturer recommended hexazinone rates for forest site preparation range from 2.0 to 6.7 kg a.i./ha (E.I. Du Pont De Nemours & Co., Specimen Label).

Metabolic break-down and detoxification of hexazinone varies among woody species (McNeil et al. 1984), resulting

in selective activity. Blueberries (Vaccinium spp.), for example, are known to be quite tolerant (Zutter and Zedaker 1988), while oaks (Quercus spp.), sweetgum (Liquidambar styraciflua) and sumacs (Rhus spp.) are known to be especially susceptible to hexazinone (Neary et al. 1981, Griswold et al. 1984, Miller 1984, Zutter and Zedaker 1988).

Questions concerning the impacts of chemical site preparation treatments on dynamics of understory plant communities remain largely unanswered. Swindel et al. (1989) and Neary (1991) demonstrated that forest herbicides, when repeatedly applied, alter species-abundance relationships and substantially diminish the plant diversity of young pine plantations. Neary (1991) suggested that single herbicide treatments, such as those used for site preparation, result in initial suppression of plant diversity followed by a recovery along a trajectory similar to that of an untreated site. Studies of plant community changes following hexazinone applications support this postulate by demonstrating that numbers of species in plant communities are unchanged, or slightly higher, during the second growing season following herbicide applications (Blake et al. 1987). In contrast, Zutter and Zedaker (1988) found that woody plant diversities of loblolly pine (Pinus taeda) plantations decreased with increasing hexazinone rates for at least two years following release applications.

Although long-term studies are most desirable in determining likely influences of chemical site preparation

on biological diversity at a variety of scales, preliminary questions must be asked, and their corresponding hypotheses tested. Prior to posing questions concerning impacts of hexazinone on plant species richness and diversity, it must be determined whether there are consistent patterns of responses among forest sites -- at least within a confined geographical area.

Plant species richness and diversity are largely determined by interspecific competition interacting with site productivity, micro-site heterogeneity, and disturbance regimes (Tilman 1982). The goal of a herbicide application is to selectively kill plants and alter the competitive relationships among plants. So, one could anticipate qualitatively different impacts of chemical site preparation on species diversity and richness among sites with dissimilar plant communities and site characteristics. This overall hypothesis was tested by examining hexazinone rate-response relationships of early successional plant communities along a generalized edaphic gradient.

Primary goals of this study were to determine initial plant community response to a series of hexazinone applications and to determine if overall plant community response in the lower Coastal Plain is similar among xeric, mesic, and hydric sites. The objectives were 1) estimate hexazinone rate response models for individual plant species, 2) determine how plant species richness, diversity, and dominance varies as a function of hexazinone rate on

three sites; and 3) determine if plant community responses to hexazinone site preparation are qualitatively the same across a gradient of forest sites.

Underlying null hypotheses were: (i) species composition is not affected by hexazinone, (ii) species richness, diversity, and dominance are not affected by increasing hexazinone rate, and (iii) responses of plant communities to hexazinone site preparation are qualitatively similar across a range of forest sites in the lower Coastal Plain.

Methods

Study Sites

Areas chosen for experimental applications were within three clearcut stands on privately-owned, commercial forestlands in north-central Florida. The sites were classified as xeric sandhill, mesic flatwoods and hydric hammock. All three sites were scheduled by land managers for aerial applications of hexazinone (Velpar ULW™) in the late spring of 1990.

The xeric sandhill site was in Gilchrist County, approximately 10 km west of the town of High Springs (29° 50'N, 82° 45'W). The site was clearcut harvested in 1988 following the first rotation of a slash pine (Pinus elliottii) plantation (approximately 20 years). Soils are well-drained, deep, acidic sands of the Penney series (thermic, uncoated Typic Quartzipsamments).

The mesic flatwoods site was in Alachua County, approximately 4 km south and 3 km east of Waldo (29° 45'N, 82° 10'W). Most of the surrounding landscape was intensively managed slash pine plantation, typical of the flatwoods of north-central Florida. Prior to clearcut harvest in early 1989, the site was occupied by a mixed-aged (18-25 years-old) slash pine plantation that had developed a mixed pine-hardwood canopy during the previous rotation.

Soils of the mesic flatwoods site are of the Sparr series (loamy, siliceous, hyperthermic Grossarenic Paleudults). Although this soil is somewhat poorly drained, the site is characterized as being a mesic flatwoods when compared with the poorly drained Spodosols that are generally found in this area (Brown et al. 1990).

The hydric hammock site was located in the Gulf Hammock area of Levy County, Florida, approximately 15 km west and 8 km south of the town of Otter Creek (29° 15'N, 82° 50'W). Hydric hammock is a distinctive type of forested, freshwater wetland. The vegetation is most similar to southern bottomland hardwoods, except that it is not as closely associated with a riverine system -- and the dominant natural vegetation is evergreen (Vince et al. 1989). The experimental site was located within what had been a natural stand of hydric hammock until clearcut harvest in the winter of 1988.

Soils of the hydric hammock site are poorly drained, shallow, loamy textured marine sediments, typically with a

black organic muck extending to a sandy clay loam at 9 cm. Limestone bedrock is within 30 cm of the surface, frequently extending up to the surface. These soils are classified as a Waccasassa (loamy, siliceous, Thermic Lithic Haplaquepts) -Demory (loamy, siliceous, Thermic Lithic Haplaquolls) complex. These areas are subjected to annual flooding and remain inundated for 1 to 3 months of the year, usually in late summer and fall.

Treatments

On 29 May, 30 May, and 16 June 1990, hexazinone was applied at four rates [0.0 (control), 1.7, 3.4, and 6.8 kg a.i./ha] within 900-m^2 plots (30 X 30 m) at the xeric sandhill, mesic flatwoods, and hydric hammock study sites, respectively. Twelve plots had been previously designated at each site and arranged in three blocks of four, with a minimum 5 m buffer between each plot. The four herbicide rates were randomly assigned to the remaining plots within each block. The experimental design was a randomized complete block.

On the mesic flatwoods and xeric sandhill, appropriate amounts of hexazinone were applied as Pronone 10G™ from a modified, hand-held, fertilizer spreader. The spreader was calibrated for a precise application at the highest treatment rate (64 kg/ha product) and was diluted with manufacturer-supplied "blank" carrier granules to the appropriate effective concentrations for the two lower application rates. Vegetation was too tall for this method

of application on the hydric hammock site, so applications were made using Velpar ULW™ from a modified Solo™ power blower.

Measurements

Prior to herbicide application, four 20-m line transects were permanently established within each plot. Lines were parallel, spaced 5 m apart, and were on a 5 m offset-stagger across a 25 X 25 m measurement plot centered within each treatment plot. Foliar cover by all woody species, and by those forb species that commonly reached heights >0.5 m, were measured along the entire length of each line. Cover by all other herbaceous vegetation was measured along three 2-m transects equally spaced along each 20-m line. Foliar cover was remeasured after the first (Oct 90) and second (Sep 91) growing seasons following treatment. Unless otherwise noted, taxonomic treatment of plant species followed Wunderlin (1982).

Data Analyses

For all three sampling periods, three diversity measures were computed separately for woody and herbaceous vegetation for each treatment replicate per site. These were (Hill 1973):

N_0 = total number of species,

$N_1 = \text{Exp}[-\Sigma_i\ p_i \ln(p_i)]$, and

$N_2 = 1/\Sigma_i\ p_i^2$,

where p_i is proportional cover of the ith species. These diversity measures represent actual units of species numbers

(Hill 1973, Ludwig and Reynolds 1988). Diversity measures N_1 and N_2 are increasingly influenced by equitable distribution of cover among the component species of a community, such that they become, respectively, more insensitive to relatively rare species.

For each study site, herbaceous cover, woody cover, N_0, N_1, N_2, and cover by individual species were tested for treatment response by analysis of covariance (ANCOVA) for a randomized complete block design. Coefficients of variation for foliar cover tended to remain constant among treatment means, so those data were log transformed to stabilize variance. Model sums of squares were partitioned into linear, quadratic, and lack-of-fit components. To avoid redundancy in reporting, species of the same genus (family in the case of Cyperaceae) were grouped if they displayed similar response trends. Taxonomic groups presented are only those for which significant ($P<0.05$) rate responses were found, or those that were non-responsive to treatment ($P>0.90$). A detailed listing of all species and scientific authorities are presented in the Appendix.

Log-normal frequency distributions (Preston 1948) and dominance-diversity curves (Whittaker 1965) were used to graphically represent changes in species-abundance relationships associated with treatment rates. These were contrasted across study sites.

Results

Xeric Sandhill

Species response. Among the eight taxonomic groups that accounted for 89% of pretreatment woody plant cover ($\bar{X}$=30%) on the xeric sandhill, only oaks, winged sumac (Rhus copallina), and sand blackberry (Rubus cuneifolius) were susceptible to hexazinone rates $\geq$ 1.7 kg/ha (Table 2-1). Greenbriers (Smilax spp.) were susceptible at rates $\geq$3.4 kg/ha. Carolina jessamine (Gelsemium sempervirens) was immediately released at intermediate rates, and became the dominant woody species by the end of the second growing season at 1.7 and 3.4 kg/ha (59 and 62% of woody cover, respectively). Pawpaw (Asimina spp.) showed a decreasing trend over time regardless of treatment, but ANCOVA indicated a linear increase with increasing hexazinone rates in relation to its pretreatment cover. Deerberry (Vaccinium staminium) and sparkleberry (V. arboreum) did not respond to hexazinone at any rate tested (P>0.90). At 6.8 kg/ha, Vaccinium spp. accounted for 71% of second season woody plant cover, while only accounting for 27% at pretreatment. Vaccinium spp. did not increase, however, in absolute cover through the study period. Sand blackberry recovered by the end of the second growing season to levels at which significant treatment effects could not be demonstrated -- but this species did not recover at 6.8 kg/ha. Oaks did not recover by the end of the second growing season, while

Table 2-1. Mean cover and herbicide rate response for plant taxa before (PT), one (Y1), and two (Y2) growing seasons after hexazinone application on a xeric sandhill site in Gilchrist County, Florida.

Life form / Taxon	Time	Hexazinone rate (kg/ha) 0.0	1.7	3.4	6.8	Rate response[a]
Woody		------ Foliar cover (%) -------				
Quercus spp.	PT	15.03	13.72	15.22	16.81	
	Y1	16.27	0.54	0.00	0.00	LOF ***
	Y2	27.23	0.96	0.08	0.00	-LIN ***
Rhus copallina	PT	1.30	1.36	2.74	2.33	
	Y1	2.17	0.46	0.00	0.00	-LIN **
	Y2	6.10	4.04	0.90	0.08	-LIN *
Vaccinium stamineum	PT	4.06	3.50	1.90	5.70	
	Y1	3.04	2.92	1.27	4.40	NS
	Y2	2.88	2.38	1.69	5.10	NS
Gelsemium sempervirens	PT	0.50	2.95	3.26	0.55	
	Y1	0.65	14.25	3.92	0.13	LOF **
	Y2	1.21	26.35	12.25	1.08	LOF **
Rubus cuneifolius	PT	0.77	0.73	1.59	0.07	
	Y1	1.48	0.29	0.00	0.00	-LIN *
	Y2	1.02	0.38	0.44	0.00	ns
Vaccinium arboreum	PT	0.61	2.40	1.28	2.65	
	Y1	0.83	2.90	1.44	2.50	NS
	Y2	0.71	2.69	1.77	1.79	NS
Smilax spp.	PT	0.30	0.82	0.38	0.22	
	Y1	0.69	0.88	0.04	0.02	-LIN
	Y2	0.63	2.54	0.58	0.10	ns
Asimina spp.	PT	0.96	1.56	1.05	0.48	
	Y1	0.23	1.23	1.27	0.71	+LIN **
	Y2	0.23	1.15	0.50	0.33	+LIN *
Grasses						
Dichanthelium spp.	PT	9.96	15.73	11.52	12.50	
	Y1	17.15	0.90	0.00	0.00	-LIN **
	Y2	14.78	4.99	9.00	4.29	-LIN *
Paspalum setaceum	PT	2.08	1.01	2.56	0.00	
	Y1	4.15	0.14	0.00	0.00	-LIN *
	Y2	2.96	2.82	8.85	6.01	LOF *

Table 2-1--continued.

Life form / Taxon	Time	Hexazinone rate (kg/ha) 0.0	1.7	3.4	6.8	Rate response
Grasses		------- Foliar cover (%) ------				
Andropogon spp.	PT	2.34	1.01	3.37	2.69	
	Y1	3.19	0.03	0.00	0.00	-LIN *
	Y2	1.33	1.64	1.14	1.61	ns
Aristida stricta	PT	0.25	0.28	1.64	2.64	
	Y1	0.69	0.56	0.42	0.69	-LIN *
	Y2	1.11	1.14	3.42	0.29	ns
Forbs						
Galactia spp.	PT	0.00	0.19	1.15	0.80	
	Y1	0.75	0.03	0.00	0.00	ns
	Y2	2.78	1.07	0.06	0.03	-LIN *
Eupatorium compositifolium	PT	0.48	0.76	0.00	1.30	
	Y1	1.98	0.00	0.00	0.00	-LIN *
	Y2	2.00	1.65	1.04	4.75	ns
Crotonopsis linearis	PT	1.12	1.17	1.27	1.17	
	Y1	5.80	4.57	0.00	0.00	-LIN **
	Y2	1.97	9.40	15.93	24.81	+LIN **
Cassia fasciculata	PT	0.27	0.08	0.36	0.16	
	Y1	0.00	0.00	0.00	0.00	
	Y2	1.58	7.98	10.58	8.40	QUAD *

[a] LIN, QUAD, and LOF indicate linear, quadratic and lack-of-fit response models, respectively. Response model designations followed by asterisks were significant at $P<0.05$, $P<0.01$, and $P<0.001$ for *, **, and ***, respectively. Sign (- or +) indicates direction of response with increasing hexazinone rate. Comparisons for which there was a failure to demonstrate a significant treatment response ($0.05 \geq P \leq 0.90$) were signified by "ns", while comparisons for which cover was significantly non-responsive ($P > 0.90$) were signified by "NS".

winged sumac seemed to recover only at 1.7 kg/ha of the herbicide.

Among the eight taxonomic groups that accounted for 67% of pretreatment herbaceous cover ($\bar{X}$=30%) on the xeric sandhill, all were decreased with increasing hexazinone rates during the first season (Table 2-1). When compared to other species, wiregrass (Aristida stricta) exhibited hexazinone tolerance such that it accounted for 1, 3, 54 and 62% at 0.0, 1.7, 3.4 and 6.8 kg/ha, respectively, even though it exhibited a decrease in absolute cover in the first season.

Decreasing cover by Dichanthelium spp. and milk peas (Galactia spp.) was significantly associated with increases in hexazinone rate at the end of the second growing season. The lack-of-fit term was significant for thin paspalum (Paspalum setaceum) during the second season, indicating that neither linear nor quadratic terms adequately explained increases in cover at $\geq$ 3.4 kg/ha. Partridge pea (Cassia fasciculata) was released following all treatment rates, the significant quadratic term reflecting an apex at 3.4 kg/ha. Crotonopsis linearis responded to increased hexazinone rates with a linear increase in the second growing season.

Dominance and diversity. Total woody cover decreased in response to increasing hexazinone rates, with significant linear and lack-of-fit terms during the first two post-treatment growing seasons (Table 2-2). Release of Carolina jessamine at 3.4 kg/ha masked decreases by other species,

Table 2-2. Means and ANOVA tables for woody species diversity and foliar cover one (Year 1) and two (Year 2) growing seasons after hexazinone application to a 1 year-old clearcut on a xeric sandhill site in Gilchrist County, Florida. All means were adjusted for pretreatment measurements.

Time	Hexazinone rate (kg/ha)	Woody diversity[a] N_0	N_1	N_2	Woody cover (%)
Year 1	0.0	14.5	8.9	7.0	32.2
	1.7	10.9 *[b]	2.7 *	1.5 *	22.7 **
	3.4	6.9 ***	3.8 *	2.9 *	8.1 ***
	6.8	4.3 ***	3.9 *	3.3 *	7.1 ***
Year 2	0.0	16.3	8.7	6.1	47.7
	1.7	14.6	3.3 *	2.0 *	42.0
	3.4	9.9 *	4.5	3.1	19.4 **
	6.8	6.5 **	4.6	3.8	8.7 ***
	Source	P-values			
Year 1	Pretreat (Covariate)	0.003	0.053	0.125	0.002
	Control vs. Hexazinone	<0.001	0.004	0.008	<0.001
	Rate	<0.001	0.023	0.037	<0.001
	Linear	<0.001	0.013	0.033	<0.001
	Quadratic	0.345	0.059	0.056	0.702
	Lack of fit	0.157	0.335	0.321	0.006
Year 2	Pretreat (Covariate)	0.255	0.269	0.408	0.042
	Control vs. Hexazinone	0.010	0.027	0.040	0.002
	Rate	0.009	0.121	0.151	<0.001
	Linear	0.002	0.198	0.420	<0.001
	Quadratic	0.592	0.091	0.080	0.221
	Lack of fit	0.364	0.240	0.221	0.050

[a] Hill's (1973) diversity numbers.

[b] Means followed by asterisks were significantly different from control (0.0 kg/ha hexazinone) by Least-Square Means (*=P<0.05, **=P<0.01, ***=P<0.001).

thus accounting for lack-of-fit to a linear term. Total herbaceous cover decreased in response to increasing hexazinone rates during the first season (Table 2-3). A significant quadratic term was reflective of the extreme susceptibility of the herbaceous community to rates $\geq$3.4 kg/ha, and the slightly greater coverage by the somewhat resistant wiregrass at 6.8 kg/ha. After the second season, total herbaceous cover did not vary among treatments. By the end of the second season, total woody cover slightly exceeded (1.5%) total herbaceous cover at 0.0 kg/ha. But total herbaceous cover exceeded woody cover by 9, 41, and 50% at 1.7, 3.4, and 6.8 kg/ha hexazinone, respectively.

All three woody diversity measures decreased with increasing hexazinone rates after the first season (Table 2-2). Diversity numbers for woody vegetation responded to increased hexazinone rates with significant linear decreases during the first season. Woody species richness (N_0) followed a similar trend during the second season. Values of N_1 and N_2 were lower on hexazinone treatments, especially at 1.7 kg/ha, but only approached marginal significance for a quadratic term. This was attributed to elimination of three dominant oak species and the concurrent release of Carolina jessamine at 1.7 kg/ha. These changes resulted in decreased woody species numbers in cover classes above 4% and a shift for one species (Carolina jessamine) into the 32% (upper-bound) class at 1.7 kg/ha (Figure 2-1). The lesser release of Carolina jessamine at rates $\geq$ 3.4 kg/ha

Table 2-3. Means and ANOVA tables for herbaceous species diversity and foliar cover one (Year 1) and two (Year 2) growing seasons after hexazinone application to a 1 year-old clearcut on a xeric sandhill site in Gilchrist County, Florida. All means were adjusted for pretreatment measurements.

Time	Hexazinone rate (kg/ha)	Herbaceous diversity[a] N_0	N_1	N_2	Herbaceous cover (%)
Year 1	0.0	19.9	10.3	6.8	51.3
	1.7	7.5 **[b]	3.6 **	2.6 *	15.4 **
	3.4	1.7 ***	1.8 **	1.7 *	0.8 ***
	6.8	1.3 ***	0.7 **	0.5 **	1.1 ***
Year 2	0.0	25.2	12.8	7.8	46.1
	1.7	22.3	12.4	8.5	51.3
	3.4	18.3 *	8.3 *	6.1	60.1
	6.8	13.9 *	5.6 **	3.9 *	58.4
	Source	P-values			
Year 1	Pretreat (Covariate)	0.478	0.480	0.248	0.551
	Control vs. Hexazinone	<0.001	0.001	0.004	0.003
	Rate	0.002	0.007	0.018	0.001
	Linear	<0.001	0.001	0.004	0.003
	Quadratic	0.075	0.172	0.352	0.038
	Lack of fit	0.326	0.935	0.810	0.342
Year 2	Pretreat (Covariate)	0.272	0.784	0.435	0.984
	Control vs. Hexazinone	0.031	0.026	0.243	0.342
	Rate	0.041	0.015	0.106	0.621
	Linear	0.009	0.004	0.028	0.320
	Quadratic	0.692	0.932	0.465	0.502
	Lack of fit	0.773	0.248	0.550	0.719

[a] Hill's (1973) diversity numbers.

[b] Means followed by asterisks were significantly different from control (0.0 kg/ha hexazinone) by Least-Square Means (*=P<0.05, **=P<0.01, ***=P<0.001).

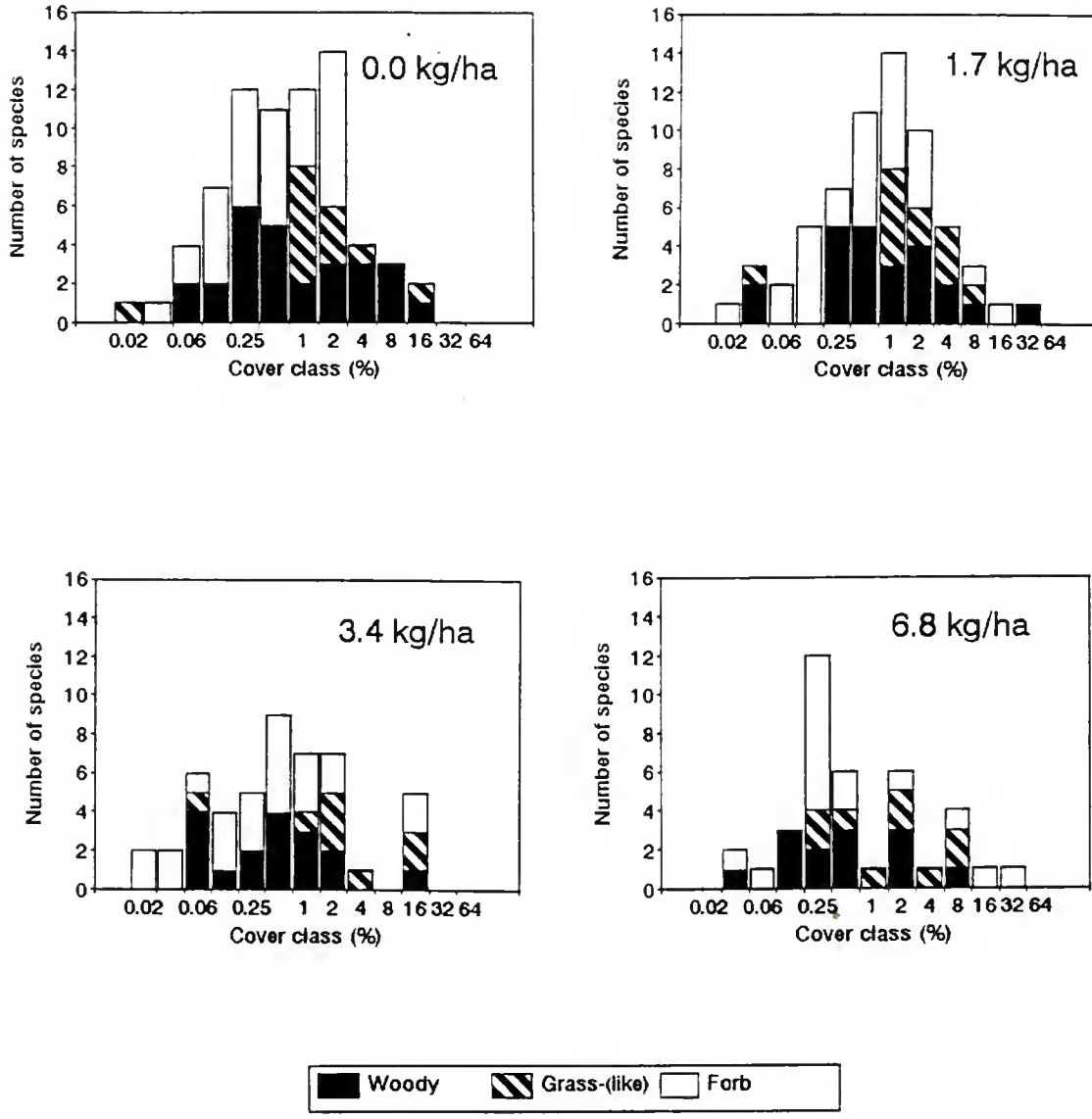

Figure 2-1. Frequency distributions of plant species across $\log_2$ cover classes (upper boundary of class denoted) at the end of the second growing season following hexazinone applications on a xeric sandhill site in Gilchrist County, Florida.

resulted in a more equitable distribution of cover among the species of greatest abundance. This was illustrated in the comparisons of dominance-diversity curves in Figure 2-2a. Even though the 1.7 kg/ha treatment plots were more species rich, N_1 and N_2 were influenced downward by increased relative dominance. Distributions of woody species in the 0.1 to 1% cover ranges were quite similar on the control (0.0 kg/ha) and 1.7 kg/ha rates, but not so at rates ≥3.4 kg/ha (Figure 2-2a).

All three herbaceous diversity measures decreased with increasing hexazinone rates during the first season (Table 2-3). During the second season, diversity measures indicated a recovery but they continued to exhibit significant linear decreases with increasing hexazinone rates. None of the herbaceous diversity measures at 1.7 kg/ha were significantly different from the untreated control.

With increasing treatment rates, progressively more species of grasses and forbs were represented in cover classes ≥4% (Figure 2-1), resulting in values for N_2 that were not significantly different from control for 1.7 and 3.4 kg/ha at the end of the second growing season. Total cover was more equitably distributed among the dominant species at 1.7 kg/ha than at 0.0 kg/ha, and accounts for the lack of a significant difference in N_2 despite the significantly lower numbers of species (N_0). This is

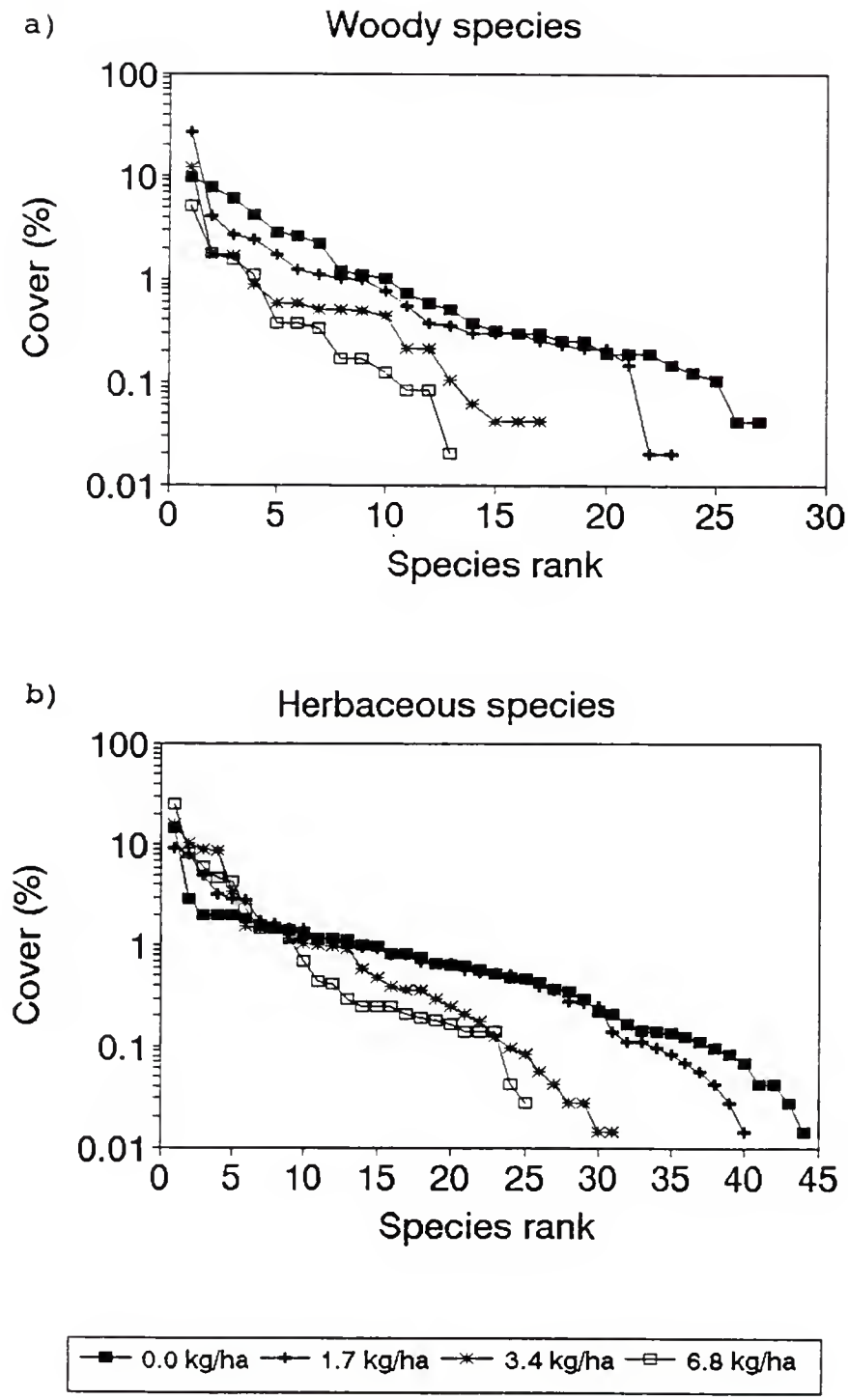

Figure 2-2. Dominance-diversity curves for plant species at the end of the second growing season following hexazinone applications on a xeric sandhill site in Gilchrist County, Florida. a) Woody species; b) Herbaceous species.

reflected in the divergence in the left tails of dominance-diversity curves in Figure 2-2b.

By the end of the second season, plant communities on hexazinone treated plots had fewer woody species of all abundance classes and more herbaceous species had gained dominance. This is reflected in Figure 2-1 by successive replacement of woody species by grass, grass-like (Cyperaceae), and forb species in cover classes ≥4%. Losses of herbaceous species were from lower (rare) portions of the abundance distribution. This is illustrated in Figure 2-2b by successively higher points-of-departure in the right tail of the dominance-diversity curves with increasing treatment rates.

Mesic Flatwoods

Species response. Of the five taxonomic groups that accounted for 92% of pretreatment woody plant cover ($\bar{X}$=11%) on the mesic flatwoods, three were susceptible to hexazinone and decreased with increasing dosage (Table 2-4). Cover response by oaks, sweetgum (Liquidambar styraciflua), and wax-myrtle (Myrica cerifera) were linear, significantly decreasing with increasing hexazinone rates during the first and second post-treatment growing seasons. During the first season, cover by Carolina jessamine and gallberry (Ilex glabra) was significantly higher on hexazinone treated sites when compared to the untreated control. Second-season responses by gallberry and Carolina jessamine were quadratically related to treatment. These two species were

Table 2-4. Mean foliar cover and herbicide rate responses for plant taxa before (PT), one (Y1), and two (Y2) growing seasons after hexazinone application on a mesic flatwoods site in Alachua County, Florida.

Life form / Taxon	Time	Hexazinone rate (kg/ha) 0.0	1.7	3.4	6.8	Rate response[a]
Woody		------ Foliar cover (%) -------				
Quercus spp.	PT	4.68	8.09	2.41	4.43	
	Y1	10.04	3.15	1.33	0.27	-LIN **
	Y2	15.46	5.02	2.00	0.88	-LIN *
Liquidambar styraciflua	PT	0.79	0.78	4.43	3.09	
	Y1	9.77	0.44	0.27	0.00	-LIN *
	Y2	14.96	1.54	0.69	0.00	-LIN *
Myrica cerifera	PT	2.43	1.58	2.14	2.16	
	Y1	3.46	1.63	0.60	0.31	-LIN *
	Y2	5.33	1.69	1.15	0.02	-LIN *
Gelsemium sempervirens	PT	0.05	0.08	0.26	0.64	
	Y1	0.92	1.42	1.90	1.85	ns
	Y2	1.35	4.94	4.17	2.29	QUAD *
Ilex glabra	PT	0.12	0.38	0.89	2.51	
	Y1	0.35	2.54	4.00	1.69	ns
	Y2	0.46	4.10	14.69	5.21	QUAD *
Grasses						
Dichanthelium spp.	PT	13.37	15.69	8.97	19.06	
	Y1	24.41	6.04	0.04	0.04	-LIN ***
	Y2	20.00	25.01	19.92	26.75	ns
Andropogon spp.	PT	1.35	0.13	0.36	0.19	
	Y1	1.24	1.99	0.00	0.00	ns
	Y2	5.19	7.81	15.68	25.29	+LIN *
Paspalum setaceum	PT	1.58	0.10	0.62	2.03	
	Y1	6.85	2.33	1.11	0.00	-LIN *
	Y2	2.68	7.33	2.83	4.68	ns
Axonopus affinis	PT	0.82	0.29	0.03	0.32	
	Y1	2.69	3.13	0.00	0.00	ns
	Y2	0.92	10.00	0.00	0.00	LOF *
Grass-likes						
Cyperus retrorsus	PT	2.18	2.18	2.51	0.76	
	Y1	4.65	2.19	0.62	0.03	-LIN *
	Y2	0.14	0.68	0.50	2.04	ns

Table 2-4--continued.

Life form / Taxon	Time	Hexazinone rate (kg/ha) 0.0	1.7	3.4	6.8	Rate response
Forbs		------ Foliar cover (%) -------				
Eupatorium compositifolium	PT	0.07	0.33	1.57	0.19	
	Y1	4.29	0.00	0.00	0.00	LOF **
	Y2	7.31	2.52	3.46	1.33	-LIN *
Cassia nictitans	PT	0.13	0.14	0.00	0.15	
	Y1	8.44	0.69	0.00	0.00	-LIN *
	Y2	3.48	8.25	2.58	1.00	ns
Eupatorium capillifolium	PT	0.17	0.00	0.00	0.00	
	Y1	1.90	0.00	0.00	0.00	ns
	Y2	1.38	0.54	2.06	6.35	+LIN *

[a] LIN, QUAD, and LOF indicate linear, quadratic and lack-of-fit response models, respectively. Response model designations followed by asterisks were significant at $P<0.05$, $P<0.01$, and $P<0.001$ for *, **, and ***, respectively. Sign (- or +) indicates direction of response with increasing hexazinone rate. Comparisons for which there was a failure to demonstrate a significant treatment response ($0.05 \geq P \leq 0.90$) were signified by "ns".

released at intermediate treatment rates (1.7 and 3.4 kg/ha hexazinone), and were slightly suppressed at 6.8 kg/ha.

All eight of the taxonomic groups that accounted for 85% of pretreatment herbaceous cover ($\bar{X}$=22%) on the mesic flatwoods were decreased with increasing hexazinone rates (Table 2-4). Although a significant treatment response could not be demonstrated for broomsedge (Andropogon spp.) and carpetgrass (Axonopus affinis) during the first year, elimination of the small amounts of those species that did occur at pretreatment on plots treated with rates $\geq$3.4 kg/ha, indicated that these species were susceptible.

Dichanthelium spp., thin paspalum, nutsedge (Cyperus retrorsus), and wild sensitive plant (Cassia nictitans) recovered during the second season to levels not significantly related to treatment rate. Cover by broomsedge increased with increasing rates during the second growing season, becoming a dominant species on the two highest treatment rates. Carpetgrass was released at 1.7 kg/ha but eliminated by the two higher rates, resulting in a significant lack-of-fit term. Eupatorium compositifolium linearly decreased with increasing hexazinone rates, while E. capillifolium linearly increased with increasing rates.

Dominance and diversity. Total woody cover at the end of the first season decreased with increasing hexazinone rates (Table 2-5). Block by treatment interactions resulted in a failure to demonstrate statistical significance in the obvious downward trend in woody cover during the second

Table 2-5. Means and ANOVA tables for woody species diversity and foliar cover one (Year 1) and two (Year 2) growing seasons after hexazinone application to a 1 year-old clearcut on a mesic flatwoods site in Alachua County, Florida. All means were adjusted for pretreatment measurements.

Time	Hexazinone rate (kg/ha)	Woody diversity[a] N_0	N_1	N_2	Woody cover (%)
Year 1	0.0	10.3	5.7	4.5	26.2
	1.7	7.2 *	4.1	3.0	11.8
	3.4	7.2 *	4.0	3.0	8.3 *
	6.8	2.2 **	2.0 *	1.9 *	6.3 **
Year 2	0.0	11.2	6.1	4.9	42.8
	1.7	10.1	5.2	4.0	22.4
	3.4	9.6 *	3.8	2.5 *	24.5
	6.8	5.5 ***	2.6 *	2.2 *	16.3
	Source	P-values			
Year 1	Pretreat (Covariate)	0.070	0.303	0.473	0.775
	Control vs. Hexazinone	0.003	0.054	0.050	0.019
	Rate	0.004	0.040	0.053	0.040
	Linear	<0.001	0.008	0.011	0.008
	Quadratic	0.762	0.942	0.706	0.528
	Lack of fit	0.160	0.642	0.542	0.792
Year 2	Pretreat (Covariate)	0.049	0.218	0.188	0.456
	Control vs. Hexazinone	<0.001	0.050	0.061	0.129
	Rate	<0.001	0.040	0.065	0.427
	Linear	<0.001	0.008	0.016	0.187
	Quadratic	0.035	0.805	0.400	0.426
	Lack of fit	0.274	0.919	0.790	0.452

[a] Hill's (1973) diversity numbers.

[b] Means followed by asterisks were significantly different from control (0.0 kg/ha hexazinone) by Least-Square Means (*=P<0.05, **=P<0.01, ***=P<0.001).

season. This resulted because of disproportionate release of gallberry in one 6.8 kg/ha replicate.

Total herbaceous cover decreased with increasing hexazinone rates during the first season and was completely eliminated by hexazinone rates of 6.8 kg/ha (Table 2-6). Total herbaceous cover did not vary with treatment during the second growing season. By the end of the second season, total herbaceous cover exceeded total woody cover by 12, 55, 44, and 56% at hexazinone rates of 0.0, 1.7, 3.4, and 6.8 kg/ha, respectively

All three measures of woody diversity decreased with increasing hexazinone rates at the ends of both post-treatment growing seasons (Table 2-5). Values of N_1 and N_2 were decreased at 3.4 kg/ha from the first into the second season due to dominance by gallberry. Mean numbers of woody species per plot (N_0) at 1.7 kg/ha were not significantly different from control. In addition, occurrence of some quantitatively rare species on one of the 1.7 kg/ha plots, resulted in comparatively more species in the smaller cover classes (Figure 2-3). The 1.7 kg/ha plots had fewer woody species in common among themselves than did 0.0 kg/ha plots, resulting in a higher combined species richness (longer right tail in Figure 2-4a).

Herbaceous diversity numbers responded to increasing hexazinone rates with significant linear decreases during the first season post-treatment (Table 2-6). Herbaceous diversity numbers N_0 and N_2 did not significantly respond to

Table 2-6. Means and ANOVA tables for herbaceous species diversity and foliar cover one (Year 1) and two (Year 2) growing seasons after hexazinone application to a 1 year-old clearcut on a mesic flatwoods site in Alachua County, Florida. All means were adjusted for pretreatment measurements.

Time	Hexazinone rate (kg/ha)	Herbaceous diversity[a] N_0	N_1	N_2	Herbaceous cover (%)
Year 1	0.0	9.0	6.8	4.4	61.0
	1.7	9.5	4.2	4.0	20.7 *
	3.4	5.6	2.3 **	2.0 *	4.4 *
	6.8	0.2 *	0.6 **	0.6 **	0.0 **
Year 2	0.0	12.4	8.4	5.8	54.9
	1.7	17.3	6.5	4.9	76.9
	3.4	16.1	7.1	5.0	68.2
	6.8	16.1	5.6 *	3.4	72.0
	Source	P-values			
Year 1	Pretreat (Covariate)	0.06	0.114	0.452	0.564
	Control vs. Hexazinone	0.177	0.005	0.013	0.007
	Rate	0.027	0.003	0.004	0.026
	Linear	0.008	0.001	0.001	0.006
	Quadratic	0.515	0.682	0.768	0.415
	Lack of fit	0.392	0.538	0.186	0.747
Year 2	Pretreat (Covariate)	0.214	0.223	0.883	0.136
	Control vs. Hexazinone	0.118	0.065	0.287	0.278
	Rate	0.372	0.106	0.380	0.655
	Linear	0.248	0.026	0.115	0.531
	Quadratic	0.244	0.597	0.858	0.541
	Lack of fit	0.241	0.221	0.686	0.426

[a] Hill's (1973) diversity numbers.

[b] Means followed by asterisks were significantly different from control (0.0 kg/ha hexazinone) by Least-Square Means (*=$P<0.05$, **=$P<0.01$, ***=$P<0.001$).

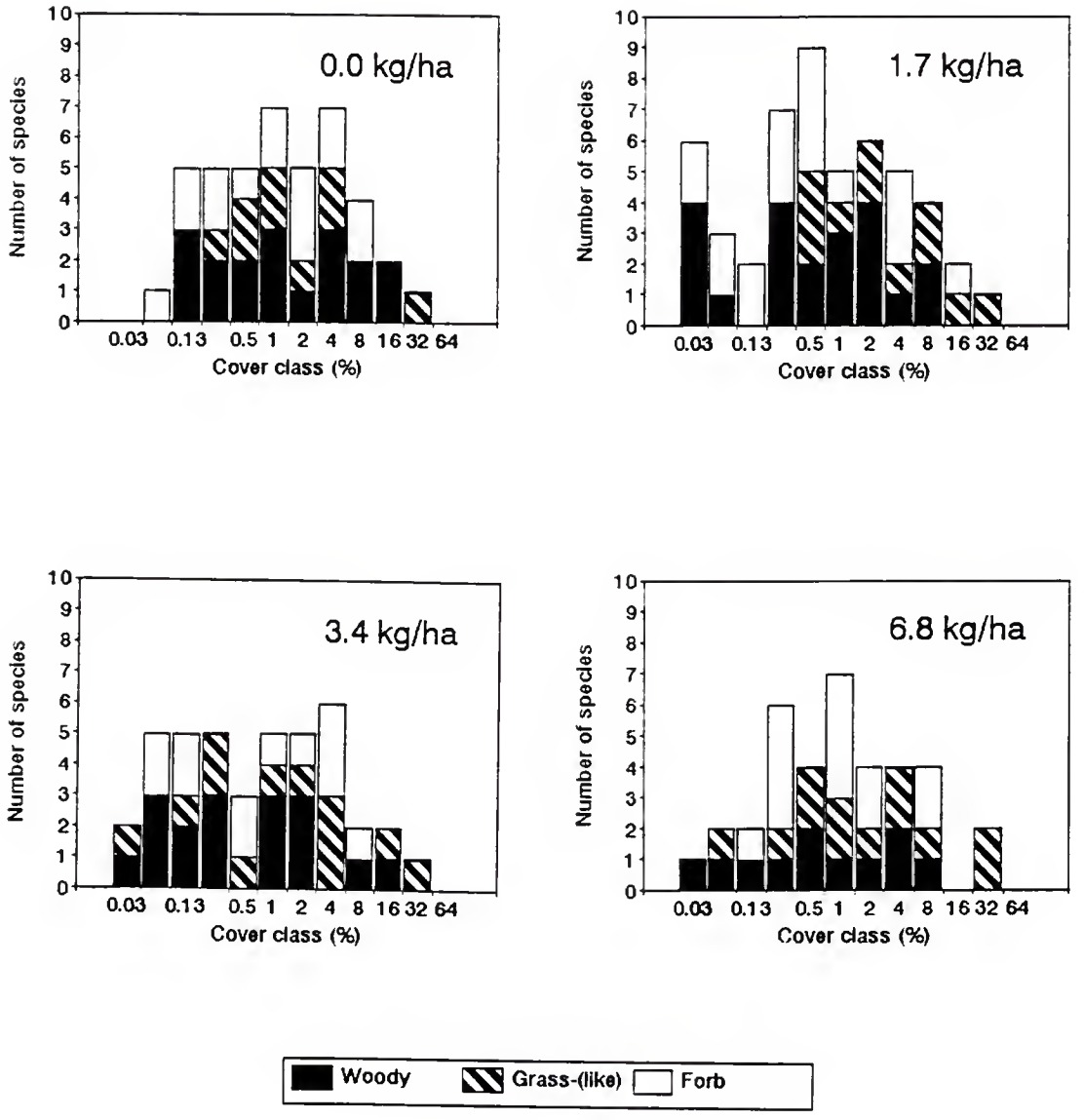

Figure 2-3. Frequency distributions of plant species across $\log_2$ cover classes (upper boundary of class denoted) at the end of the second growing season following hexazinone applications on a mesic flatwoods site in Alachua County, Florida.

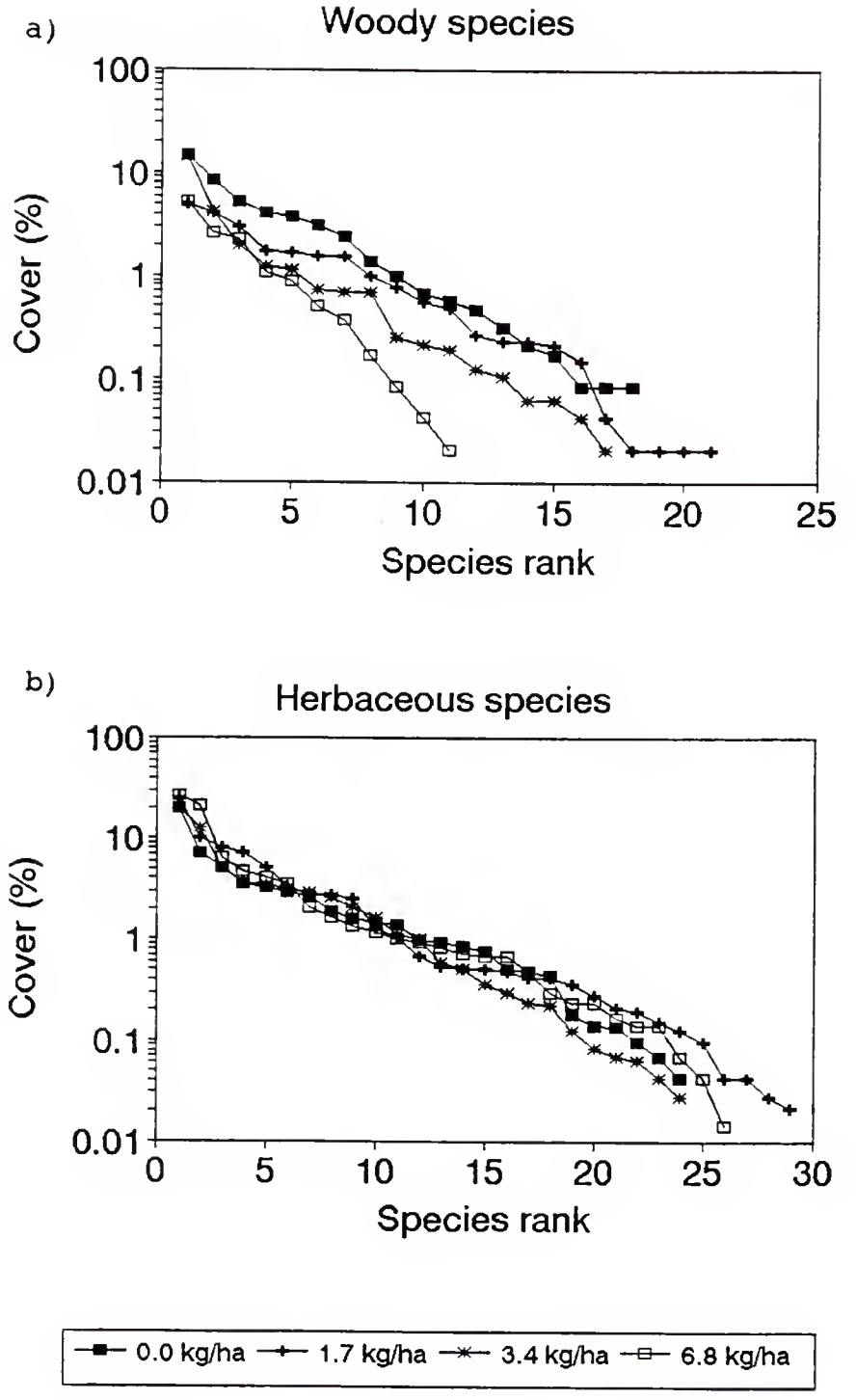

Figure 2-4. Dominance-diversity curves for plant species at the end of the second growing season following hexazinone applications on a mesic flatwoods site in Alachua County, Florida. a) Woody species; b) Herbaceous species.

treatment during the second season. However, N_1 decreased with increasing hexazinone rates. Figure 2-3 illustrates the successive shifts of herbaceous species into larger cover classes as hexazinone rate increased. At 6.8 kg/ha, two species (Dichanthelium spp. and broomsedges) were in the 32% cover class, while 15 species covered ≤1% each. Dominance-diversity curves illustrated only minor departures (Figure 2-4b) and no treatment related responses could be discerned.

Hydric Hammock

Species response. Cover by each of the nine taxonomic groups that accounted for 80% of pretreatment woody cover ($\bar{X}$=47%) tended to decrease with increased rates of hexazinone (Table 2-7). Sea-myrtle (Baccharis halimifolia), sweetgum, grapes (Vitis spp.), and cabbage palm (Sabal palmetto) responded to increased hexazinone rates with linear decreases in cover during both the first and second growing seasons following treatment. Hornbeam (Carpinus caroliniana) cover during the second season was lowest on all treatment plots even though the statistical response was quadratic. The pretreatment covariate was significant (P=0.05), thus impacting that trend. Greenbrier (Smilax spp.) responded to increases in hexazinone rate by linearly decreasing during the first season. Greenbrier cover decreased from the first to the second season following all treatments such that second-season means were the same. Red bay (Persia borbonia) and persimmon (Diospyros virginiana),

Table 2-7. Mean foliar cover and herbicide rate response for plant taxa before (PT), one (Y1), and two (Y2) growing seasons after hexazinone application on a hydric hammock site in Levy County, Florida.

Life form / Taxon	Time	Hexazinone rate (kg/ha) 0.0	1.7	3.4	6.8	Rate response[a]
Woody		------ Foliar cover (%) -------				
Baccharis halimifolia	PT	14.53	9.73	9.63	10.73	
	Y1	43.17	23.52	8.23	2.25	-LIN ***
	Y2	47.23	35.95	20.06	5.70	-LIN ***
Liquidambar styraciflua	PT	8.71	6.29	7.39	11.09	
	Y1	15.93	5.08	1.65	0.52	-LIN ***
	Y2	23.23	7.69	1.83	0.23	-LIN **
Vitis spp.	PT	11.85	4.36	15.32	2.13	
	Y1	12.58	1.63	0.46	0.00	-LIN ***
	Y2	15.50	4.02	1.90	0.23	-LIN **
Sabal palmetto	PT	3.85	1.22	1.94	1.45	
	Y1	6.22	2.54	1.94	1.67	-LIN *
	Y2	6.49	2.10	2.27	1.83	-LIN *
Quercus spp.	PT	5.00	4.10	1.86	1.50	
	Y1	3.85	2.50	0.96	0.29	ns
	Y2	4.31	2.23	0.69	0.06	-LIN **
Carpinus caroliniana	PT	2.44	2.25	4.38	2.72	
	Y1	1.76	0.75	0.10	0.83	ns
	Y2	4.06	1.44	1.73	2.33	QUAD *
Smilax spp.	PT	3.68	3.16	3.67	2.57	
	Y1	4.74	2.80	2.16	1.10	-LIN *
	Y2	1.88	1.50	1.15	1.00	NS
Persia borbonia	PT	0.24	0.39	0.79	0.56	
	Y1	0.56	0.50	0.19	0.00	-LIN **
	Y2	1.37	1.95	0.81	0.33	ns
Diospyros virginiana	PT	0.30	0.73	0.33	1.74	
	Y1	0.55	0.00	0.00	0.23	QUAD **
	Y2	1.09	1.42	0.08	0.10	ns
Grass-like						
Cyperaceae (*Rhynchospora-Carex* spp.)	PT	71.38	51.69	50.02	68.89	
	Y1	62.89	35.23	22.77	13.77	-LIN **
	Y2	39.93	29.88	29.54	35.88	NS

Table 2-7--continued.

Life form / Taxon	Time	Hexazinone rate (kg/ha) 0.0	1.7	3.4	6.8	Rate response
Grasses		------- Foliar cover (%) -------				
Chasmanthium laxum	PT	12.10	3.78	18.20	17.86	
	Y1	2.86	0.00	0.58	0.06	ns
	Y2	8.57	5.26	8.82	1.60	-LIN *
Andropogon spp.	PT	7.85	6.57	5.57	2.51	
	Y1	11.50	8.42	6.95	5.62	ns
	Y2	7.01	21.88	19.31	17.93	QUAD **
Dichanthelium commutatum	PT	11.68	18.90	18.23	6.18	
	Y1	7.44	8.26	11.37	4.89	ns
	Y2	3.87	10.50	8.99	9.88	+LIN *
Forbs						
Eupatorium capillifolium	PT	9.47	8.98	8.48	8.21	
	Y1	37.23	4.29	0.00	0.00	LOF ***
	Y2	1.18	1.79	9.92	23.12	+LIN ***
Mikania scandens	PT	0.89	1.02	0.71	0.41	
	Y1	1.17	1.29	1.31	0.00	QUAD **
	Y2	0.49	1.17	6.35	4.74	QUAD **

[a] LIN, QUAD, and LOF indicate linear, quadratic and lack-of-fit response models, respectively. Response model designations followed by asterisks were significant at $P<0.05$, $P<0.01$, and $P<0.001$ for *, **, and ***, respectively. Sign (- or +) indicates direction of response with increasing hexazinone rate. Comparisons for which there was a failure to demonstrate a significant treatment response ($0.05 \geq P \leq 0.90$) were signified by "ns", while comparisons for which cover was significantly non-responsive ($P > 0.90$) were signified by "NS".

both of which decreased due to treatment during the first season, recovered somewhat during the second season such that a significant treatment response could not be detected.

Among the six taxonomic groups that accounted for 87% of the pretreatment herbaceous cover ($\bar{X}$=117%), only Cyperaceae (Rhynchospora spp. - Carex spp. complex) showed a linear decrease with increasing hexazinone rates during the first season. Broomsedges were increased on hexazinone treatments during the second season, but the response was quadratic. Cover measurements of Dichanthelium commutatum were highly variable during the first season resulting in a non-significant response. This was followed, however, by a significant linear increase with increasing herbicide rates during the second season. During the first season, a lack-of-fit term was highly significant for Eupatorium capillifolium, indicating that neither the linear nor quadratic terms adequately explained the obvious decreases due to treatment. E. capillifolium recovered during the second season, responding linearly to increased hexazinone rates. Broomsedge was probably out-competed by E. capillifolium at 3.4 and 6.8 kg/ha resulting in a significant quadratic response during the second season. Quadratic terms were significant for climbing hempweed (Mikania scandens) during both post-treatment seasons. Climbing hempweed cover was greatest at 3.4 kg/ha, slightly decreasing at 6.8 kg/ha.

Dominance and diversity. Total woody cover responded to increasing hexazinone rates with a highly significant linear decrease during the first and second seasons (Table 2-8). Total herbaceous cover responded with a highly significant linear decrease during the first season (Table 2-9). During the second season, total herbaceous cover responded with a highly significant linear increase. By the end of the second season, total woody cover exceeded total herbaceous cover by 38% at 0.0 kg/ha, but total herbaceous cover exceeded total woody cover by 28, 74, and 107% at 1.7, 3.4, and 6.8 kg/ha, respectively.

Species richness (N_0) of woody vegetation decreased linearly with increased hexazinone rates during the first and second seasons due to losses of species from all abundance classes. N_1 and N_2 did not respond to treatment during the first season, yet the quadratic term was significant for during the second season. During the second season, relative cover by sea-myrtle was 53% and 58% at 1.7 and 3.4 kg/ha, respectively. All other woody species were distributed $\leq$ 8% at 1.7 kg/ha, and $\leq$4% at 3.4 kg/ha (Figure 2-5). Diversity measure N_2 was thus depressed at those two treatment rates, but not at 6.8 kg/ha where relative cover by sea-myrtle was at 38%.

Species diversity of herbaceous vegetation did not significantly respond to hexazinone treatment during the first season. During the second season, values of all three diversity measures linearly increased with increasing

Table 2-8. Means and ANOVA tables for woody species diversity and foliar cover one (Year 1) and two (Year 2) growing seasons after hexazinone application to a 1 year-old clearcut on a hydric hammock site in Levy County, Florida. All means were adjusted for pretreatment measurements.

Time	Hexazinone rate (kg/ha)	Woody diversity[a] N_0	N_1	N_2	Woody cover (%)
Year 1	0.0	19.4	7.4	4.9	92.0
	1.7	19.0	5.4	3.0	49.3 **
	3.4	15.3	7.1	4.6	16.7 ***
	6.8	11.4 *	7.4	5.8	10.0 ***
Year 2	0.0	21.1	6.9	4.5	106.8
	1.7	21.9	5.9	3.1	72.2 **
	3.4	16.6	5.5	2.8	31.1 ***
	6.8	13.0 *	7.0	5.1	17.8 ***
	Source	P-values			
Year 1	Pretreat (Covariate)	0.457	0.011	0.006	0.344
	Control vs. Hexazinone	0.097	0.476	0.590	<0.001
	Rate	0.081	0.380	0.105	<0.001
	Linear	0.020	0.577	0.114	<0.001
	Quadratic	0.849	0.395	0.141	0.193
	Lack of fit	0.532	0.157	0.105	0.118
Year 2	Pretreat (Covariate)	0.478	0.253	0.084	0.132
	Control vs. Hexazinone	0.124	0.659	0.257	<0.001
	Rate	0.058	0.746	0.087	<0.001
	Linear	0.017	0.758	0.228	<0.001
	Quadratic	0.765	0.338	0.026	0.824
	Lack of fit	0.251	0.904	0.904	0.226

[a] Hill's (1973) diversity numbers.

[b] Means followed by asterisks were significantly different from control (0.0 kg/ha hexazinone) by Least-Square Means (*=P<0.05, **=P<0.01, ***=P<0.001).

Table 2-9. Means and ANOVA tables for herbaceous species diversity and foliar cover one (Year 1) and two (Year 2) growing seasons after hexazinone application to a 1 year-old clearcut on a hydric hammock site in Levy County, Florida. All means were adjusted for pretreatment measurements.

Time	Hexazinone rate (kg/ha)	Herbaceous diversity[a] N_0	N_1	N_2	Herbaceous cover (%)
Year 1	0.0	13.3	6.5	5.1	128.4
	1.7	15.8	6.4	4.6	76.9 **
	3.4	12.8	6.5	4.5	52.5 ***
	6.8	10.6	5.9	4.5	27.6 ***
Year 2	0.0	15.1	7.9	5.8	69.0
	1.7	21.6 *	8.7	5.7	100.4 **
	3.4	17.3	10.5	8.3 *	104.8 **
	6.8	22.1 *	11.9 *	8.8 *	124.7 ***
	Source	P-values			
Year 1	Pretreat (Covariate)	0.358	0.219	0.210	0.440
	Control vs. Hexazinone	0.936	0.874	0.617	<0.001
	Rate	0.455	0.969	0.948	<0.001
	Linear	0.218	0.678	0.660	<0.001
	Quadratic	0.507	0.875	0.772	0.744
	Lack of fit	0.373	0.947	0.941	0.709
Year 2	Pretreat (Covariate)	0.872	0.232	0.102	0.207
	Control vs. Hexazinone	0.019	0.110	0.088	<0.001
	Rate	0.027	0.099	0.041	0.002
	Linear	0.027	0.024	0.012	<0.001
	Quadratic	0.647	0.818	0.653	0.877
	Lack of fit	0.019	0.657	0.142	0.320

[a] Hill's (1973) diversity numbers.

[b] Means followed by asterisks were significantly different from control (0.0 kg/ha hexazinone) by Least-Square Means (*=P<0.05, **=P<0.01, ***=P<0.001).

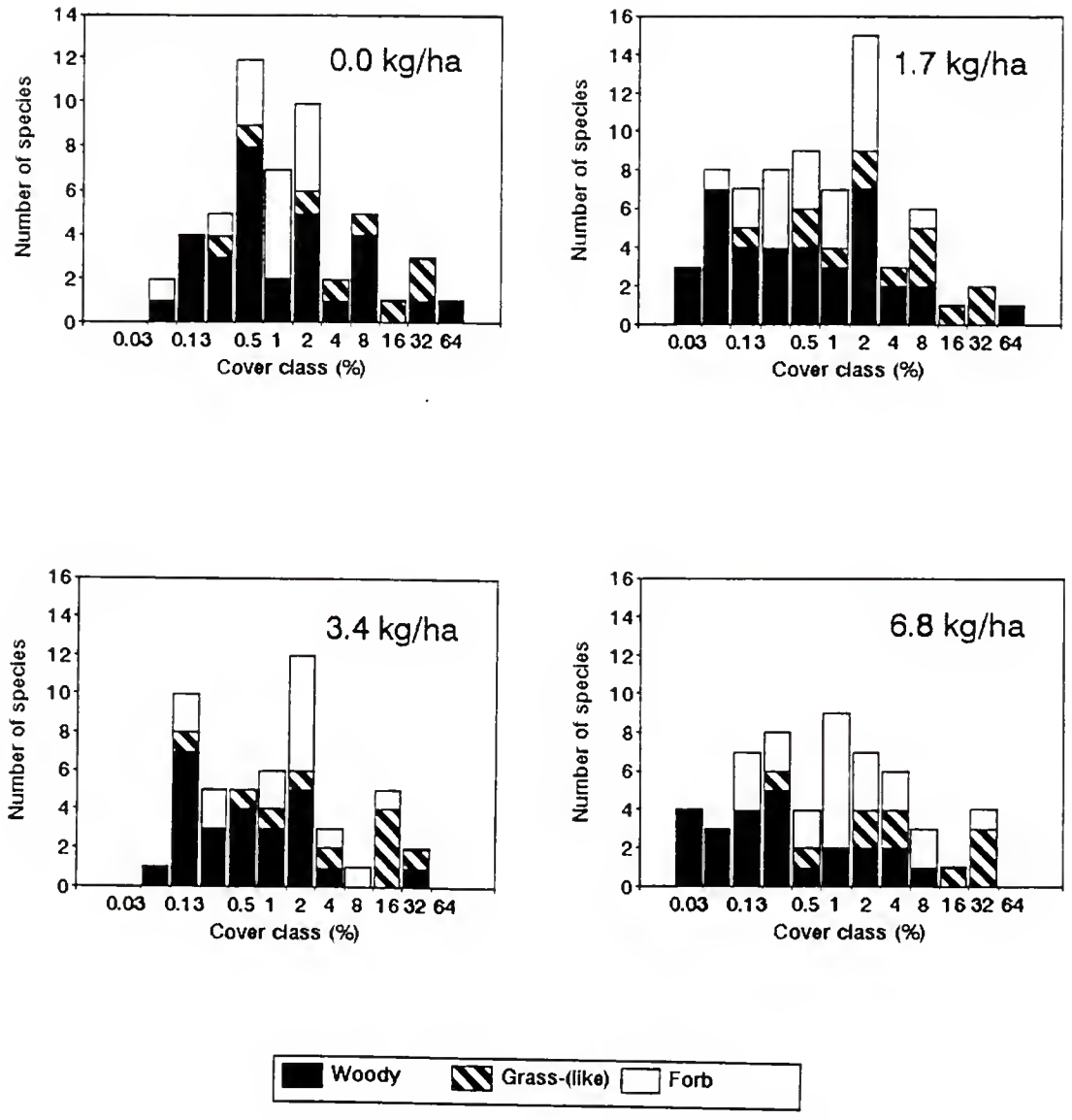

Figure 2-5. Frequency distributions of plant species across $\log_2$ cover classes (upper boundary of class denoted) at the end of the second growing season following hexazinone applications on a hydric hammock site in Levy County, Florida.

hexazinone rates. The lack-of-fit term was also significant for N_0 indicating that variability in species richness was not adequately explained by a linear response. Dominance-diversity curves for the pooled data exhibited similar relative distributions for those species with $\geq$0.5% cover (Figure 2-6b). Quadratic responses by broomsedge and climbing hempweed shifted those species into abundance classes $\geq$8% at 3.4 kg/ha (Figure 2-5) allowing relative abundance to be shared by more species, thereby compensating for lower herbaceous species numbers in determinations of N_1 and N_2.

Discussion

Species Response

Results reported here demonstrated that woody plant compositions on xeric sandhill and mesic flatwoods sites shifted largely as a result of different response models among dominant species (i.e., hexazinone acted in a selective manner on these sites). This contrasts with the responses measured for dominant woody species on the hydric hammock site, which all tended to decrease with increasing hexazinone rates.

Oak species were prominent in the pretreatment composition of all sites. Although oaks responded similarly to hexazinone on all sites (i.e., decreasing dominance with increasing hexazinone rates), the degree to which increasing hexazinone rate played a factor in oak control was quite different. For example, oaks on the xeric sandhill site

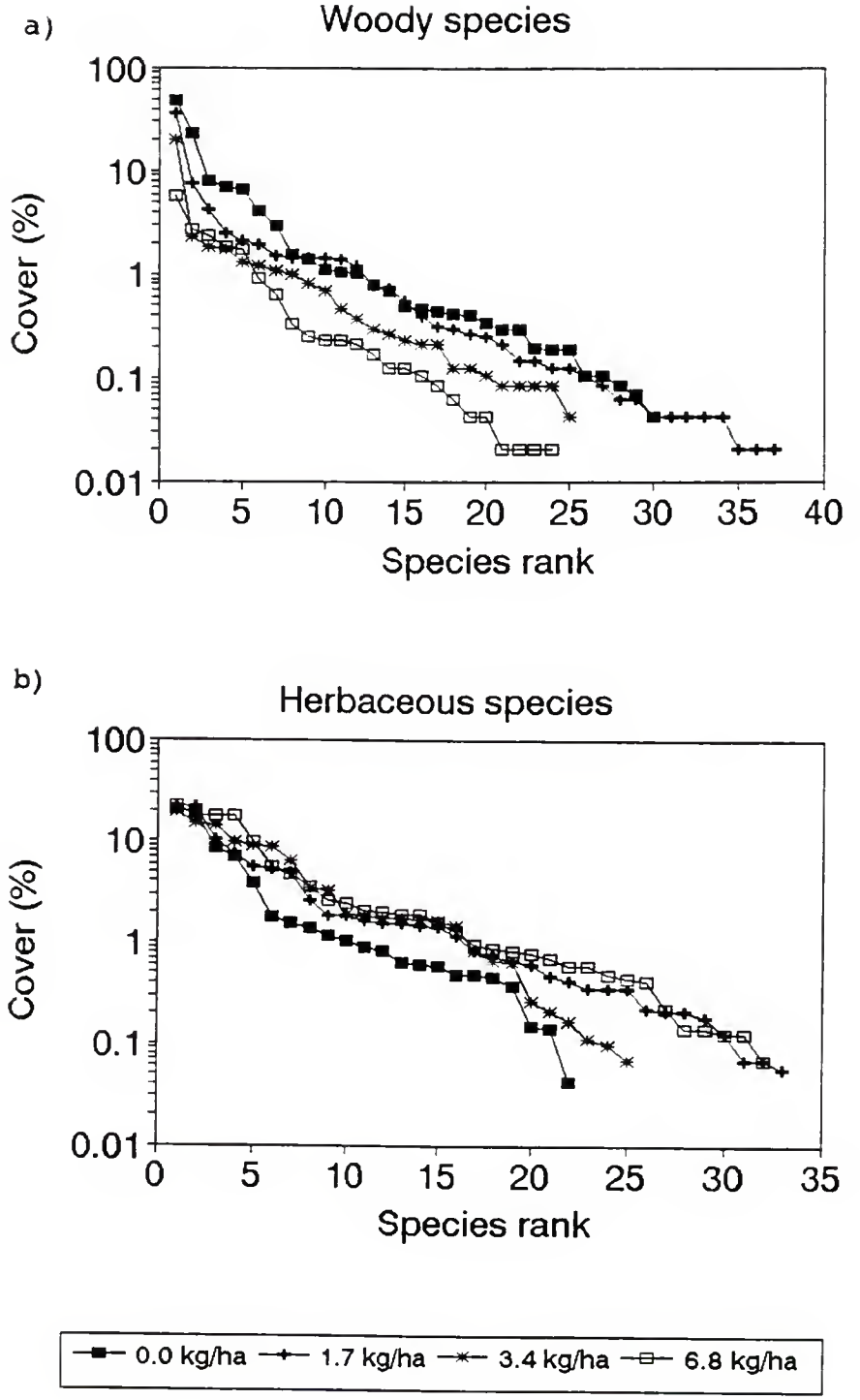

Figure 2-6. Dominance-diversity curves for plant species at the end of the second growing season following hexazinone applications on a hydric hammock site in Levy County, Florida. a) Woody species; b) Herbaceous species.

were nearly eliminated (97% reduction) at 1.7 kg/ha, while on the mesic flatwoods and hydric hammock, oak control at 1.7 kg/ha was 69% and 35%, respectively. This gradient in oak control is probably a result of interactions with hexazinone and the differing soil factors across the three sites. Effects of pelletized hexazinone formulations on oaks and other hardwood species are inhibited by fine soil textures, increased organic matter contents, and increased cation exchange capacities (Minogue et al. 1988). These soil factors all would be expected to increase across the gradient of acidic sands (xeric sandhill), to sandy loam (mesic flatwoods), to loamy organic muck (hydric hammock).

Three of the oak species that dominated on xeric sandhills (Q. incana, Q. laevis, and Q. geminata) sprout as a primary regenerative method. This is as an adaptation to fire in xeric sandhills and scrub environments (Abrahamson 1984, Myers and White 1987). Reestablishment of these oaks into areas from which their root stocks have been eliminated is slow. On the xeric sandhills site, first season eliminations of oaks from and all replicate plots at ≥3.4 kg/ha were followed by only trace recoveries at 3.4 kg/ha and no recovery at 6.8 kg/ha during the second season.

Carolina jessamine was released from competition at 1.7 and 3.4 kg/ha and became dominant and co-dominant in woody compositions on xeric sandhill and mesic flatwoods sites, respectively. Similarly, gallberry was released on the mesic flatwoods site, becoming dominant in the woody

composition at 3.4 kg/ha. Both Vaccinium species experienced an increase in relative dominance on the xeric sandhills site by virtue of their non-responsive nature to hexazinone. While the rate-response of Carolina jessamine has remained unreported in the reviewed literature, the tolerance of Vaccinium spp. to hexazinone has been documented (Zutter and Zedaker 1988, Zutter et al. 1988). Second-year responses of gallberry reported here were similar to those reported for yaupon (Ilex vomitoria) in the Post Oak Savannah of Texas (Scifres 1982), indicating that hexazinone tolerance may be a characteristic of the genus Ilex.

Carolina jessamine became a dominant species when released by hexazinone. This species is not generally considered to be a sandhills denizen, yet it is sufficiently shade tolerant and drought resistant (Godfrey 1988), and it is present in small quantities in flatwoods pine plantations adjacent to the xeric sandhills site. Sprouting from extensive underground rhizomes, some vines of Carolina jessamine were observed to extend greater than 2 m during 1 year. This species was able to grow prostrate, or climb and tangle into structure of standing dead woody stems on those plots where oaks were killed and application rates were either 1.7 or 3.4 kg/ha.

On the mesic flatwoods site, Carolina jessamine did not reach the same proportions as on the xeric sandhill apparently due to the release of gallberry. Gallberry was

present only in small quantities at pretreatment; however, its ability to aggressively invade a site by sprouting from underground rhizomes (Hughes 1964) allowed it to dominate by the second growing season at rates ≥3.4 kg/ha. More moderate reduction of oak canopies at 1.7 kg/ha on the mesic flatwoods site precluded the domination by gallberry at that rate. At 3.4 kg/ha, gallberry cover reached its peak, declining somewhat at 6.8 kg/ha. At this high rate, however, gallberry response on one replicate was still high enough to cause a treatment X block interaction, resulting in the non-significant response of total foliar cover by woody species to hexazinone rate.

Shifts in the relative composition of woody species were not as apparent on the hydric hammock site. No dominant woody taxon was completely eliminated, even at the highest treatment rate. Furthermore, there were no apparent releases of hexazinone-resistant species. The dominant woody plant at all treatment rates was sea-myrtle -- a fast-growing early-successional species that reproduces primarily from wind-dispersed seeds. So, short-term invasion of sites was not impaired as it probably was for the previously dominant species on the other study sites. While being dominant in young (1- to 3- year-old) clearcuts on hydric hammock sites, sea-myrtle apparently yields dominance to cabbage palm, Quercus nigra, and planted pines as early as 7 years later (Chapter 3).

Although Dichanthelium spp., broomsedge, and thin paspalum were susceptible to the initial impacts of hexazinone on both the xeric sandhill and mesic flatwoods sites (first season response), second season responses varied between sites. Dichanthelium spp. recovered on the mesic flatwoods but remained negatively influenced by treatment rate on the xeric sandhill. Broomsedge responded to a release from woody competition with incremental increases on the mesic flatwoods while exhibiting no response to increased rates on the xeric sandhill. Thin paspalum was apparently unable to compete with Dichanthelium spp. and broomsedge on the mesic flatwoods site, but experienced a substantial second season increase on the xeric sandhill site at rates $\geq$3.4 kg/ha. Thin paspalum was evidently better able to compete in the xeric sandhill environment.

Cover by Crotonopsis linearis, partridge pea, and E. compositifolium increased with increasing herbicide rate in the second season on the xeric sandhill. These species exhibit rapid growth, large seed crops, and relatively short life-cycles -- all adaptations described by Grime (1979) as being characteristic of a ruderal strategy. Although three forbs with these ruderal strategies were prominent on the mesic flatwoods site, only E. capillifolium responded with an increase due to increasing hexazinone rates. Competition from gallberry and broomsedge appeared to suppress

establishment of ruderal species on the mesic flatwoods site.

E. capillifolium responded in a similar manner on the hydric hammock site. Commonly reaching heights >2 m, this species became the most dominant plant above the ground-layer (>0.5 m) at 6.8 kg/ha. Dominance of this shrub-like herb at 6.8 kg/ha accounts for the suppression of broomsedge and spike chasmanthium (Chasmanthium laxum). Occurrence of climbing hempweed was associated with pretreatment occurrence of grape species, occurring on microsites not occupied by most other species (e.g., slash piles and tops of wind-thrown snags). When the competition for this structure was reduced by grape suppression following hexazinone treatment, climbing hempweed, which was fairly tolerant of hexazinone at $\leq$3.4 kg/ha, responded with increases in cover.

Community Response Across a Gradient

All sites experienced a decrease in woody species richness, and successive shifts towards domination by herbaceous vegetation as a response to increasing hexazinone rates. Effects of increasing hexazinone rates on woody diversity measures N_1 and N_2 were different among sites due to inconsistent concentrations of species-dominance. This is in contrast to Zutter and Zedaker's (1988) results that showed consistent linear decreases of Shannon-Weaver [$Log(N_1)$] and Simpson's ($1/N_2$) indices during the second growing season following hexazinone release of four loblolly

pine plantations in the southeastern United States. Diversity measures from only the mesic flatwoods site of the present study followed this same trend. At hexazinone rates of 1.1 kg/ha, Blake et al. (1987) reported second-season species richness increases for woody and herbaceous plants on a site in Mississippi. The lowest rate used in the present study was 50% greater than the single rate used in the Mississippi study, so results are not directly comparable.

Herbaceous diversity response to increasing hexazinone rates shifted along the edaphic gradient. With increases in hexazinone rate, trends during the second season were for herbaceous diversity to: 1) decrease on the xeric sandhill site; 2) be unchanged (N_0 and N_2) or slightly decreased (N_1) on the mesic flatwoods; and 3) to increase on the hydric hammock. Dominance-diversity curves also reflected dissimilarities among sites (Figures 2-2a, 2-4a, 2-6a). On the xeric sandhill, abundance distributions switched their relative ordering from the left tail (abundant species) to the right tail (rare species). This is a graphic illustration of a shift from the log-normal distribution toward a geometric distribution -- most often associated with early successional communities (Bazzaz 1975, May 1981). Abundance distributions were approximately the same on the mesic flatwoods. For the hydric hammock species, however, abundance distributions for 0.0 kg/ha rates diverged from those of hexazinone treated plots on the left tail.

Hexazinone treatments (especially those at 1.7 and 6.8 kg/ha) sustained more species of intermediate abundance.

Differences in trends of total herbaceous cover across sites were apparently functions of contrasting site productivities as well as differences in levels of competition from hexazinone-resistant woody species. Herbaceous communities on the untreated plots at the xeric sandhill site were rich in species of intermediate abundance. Many of these species have xerophytic adaptations that allow them to tolerate the droughty environment of the sandhills (Stalter 1984). Characteristics shared by most of these stress-tolerators are relatively slow growth rates and limited investment in propagules (Grime 1979). Xerophytic herbs that were initially suppressed by hexazinone were unlikely to recover during this studies duration. Xerophytic species that were not suppressed were unlikely to reach dominance because of inherently low growth rates. Ruderal species such as Crotonopsis linearis, partridge pea, and E. compositifolium were thus able to capture increasing amounts of site resources with increasing herbicide rates.

On the mesic flatwoods site, herbaceous vegetation was unable to establish and grow within extensive areas covered by gallberry clones. This suppressed herbaceous recovery was apparent on plots treated with 3.4 kg/ha, and to a lesser extent for the other rates. In absence of gallberry

competition, herbaceous recovery on the mesic flatwoods may have approximated that on the hydric hammock.

Potential plant productivity of hydric hammock sites is considered to be among the highest for forested wetlands in Florida (Ewel 1990, Vince et al. 1989), indirectly accounting for increases in total herbaceous cover with increasing hexazinone rates. Since no competitive woody species were released by hexazinone, the herbaceous vegetation responded to a release from woody competition. Each successive decrease in the woody canopy was met with a concomitant increase in total herbaceous cover.

In addition to releases from woody competition, hexazinone-related increases in herbaceous diversity were likely related to initial (first season) suppression of original herbaceous vegetation (mostly Carex spp. and Rhynchospora spp.). Opportunities for invasion by new herbaceous species were thus greater during the second season following herbicide treatment. Herbaceous flora common to disturbed hydric hammock sites are principally hydrophytic, adapted for rapid site invasion, and have extremely high growth rates. So, increased resource availability as well as herbicide-related disturbance of the herbaceous layer accounted for higher herbaceous species richness and diversity.

These results indicate that species diversity responses to hexazinone are not similar among early successional plant communities in regenerating forests of the lower Coastal

Plain. Data presented here support the hypothesis that the response of plant species diversity to a selective herbicide interacts with a generalized environmental gradient. Different diversity responses were not solely attributable to a gradient in potential site productivity (i.e., edaphic gradient). Presence or absence of woody species that were hexazinone-tolerant and capable of rapid growth had major impacts on plant diversity and species-abundance distributions.

CHAPTER 3
A COMPARISON OF THE EFFECTS OF CHEMICAL AND MECHANICAL SITE PREPARATION ON VASCULAR PLANT DIVERSITY AND COMPOSITION OF HYDRIC HAMMOCK SITES

Introduction

Hydric Hammocks and Site Preparation

Hydric hammocks are a distinctive type of forested, freshwater wetland found exclusively in temperate Florida (Vince et al. 1989). Although this forest type has site characteristics and common tree species that make it similar to bottomland hardwoods (e.g., *Liquidambar styraciflua*, *Fraxinus* spp., and *Acer* spp.) and cypress-tupelo (*Taxodium* spp. - *Nyssa* spp.) swamps, the basic evergreen character of the dominant woody species (*Quercus virginiana*, *Q. laurifolia*, *Juniperus silicicola*, *Pinus taeda*, and *Sabal palmetto*) makes hydric hammocks unique. Hydric hammocks intermingle with cypress swamps, pine flatwoods, mesic hammocks, xeric sandhills, and salt marshes, providing requisite habitat components to many vertebrate wildlife species. Per unit area, hydric hammocks are considered to be among the most critical wetlands for sustaining vertebrate wildlife communities (Wharton et al. 1981, Vince et al. 1989, Ewel 1990).

Simons et al. (1989) estimated that hydric hammocks once covered approximately 202,500 ha. Forty percent of

this area has been converted to real estate development or agricultural production, 20% has been converted to commercial loblolly pine (Pinus taeda) and slash pine (P. elliottii) plantations, 20% has been placed under public ownership (presumably not to be converted to other uses). The remaining 20% is owned by forest products companies. Conversion to pine plantations has been by clearcut harvesting, followed often by intensive mechanical site preparation such as shearing and windrowing (Hudson 1983, Simons et al. 1989, McEvoy 1990).

Conversions of natural stands to southern pine plantations have been perceived as being destructive to wildlife habitats, with negative consequences in proportion to intensity of disturbance during site preparation (Schultz and Wilhite 1974, Harris et al. 1975, White et al. 1976, Harris et al. 1979). Objective determinations of relative intensities of chemical versus mechanical techniques have not been made.

Shearing residual stems and windrowing can result in substantial transport and concentration of topsoil and organic matter into linear piles of debris, resulting in nutrient redistribution (Morris et al. 1983), long-term pine productivity losses (Swindel et al. 1986), and delayed recovery of native plant communities (Wilkins et al., in review). Prior to the recent registration of several non-phenoxy forest herbicides, windrowing was considered to be the only practical method of controlling hardwood

competition for achieving satisfactory pine survival and growth (Morris et al. 1981).

Since the early 1980's, the forest herbicide hexazinone has been available as an alternative to mechanical site preparation. Liquid hexazinone (Velpar-L™) was first tested as an aerial spray for site preparation of hydric hammock sites in 1983 (G. Galpin, pers. comm.). Although the preferred formulation of hexazinone has changed to a granular product (Velpar-ULW™), the use of both hexazinone and windrowing continues for converting natural hydric hammock stands to pine plantations on some private ownerships.

Plant Diversity

Because conservation is partially based on the concept that species-rich communities are better than species-poor communities, ecological evaluations of species richness and relative abundance (i.e., diversity studies) commonly place importance upon maintaining maximal species numbers (Magurran 1988). Reasons for this widespread conception are not well defined. The notion that increasing species diversity somehow increases ecosystem stability is considered misleading (May 1981, Zaret 1982). More stable environments, however, generally allow for the development of more complex communities, which tend to be more diverse (May 1981).

The National Forest Management Act (Federal Register 44(181), 219.13(6), 1979) requires that silvicultural

practices maintain the diversity of forest ecosystems. Because the primary goal of forest vegetation management (specifically site preparation) is to concentrate future site productivity into a preferred tree species, there is a direct conflict with the goal of maintaining plant species diversity (Zedaker 1991). A tangible method for evaluating site preparation treatments would be to determine which treatments least impact plant diversity.

Studies of plant diversity involve careful examination of species abundance relationships while disregarding taxonomic status. Despite abundant literature and theory on the subject (see Magurran 1988 for a review), definitions of issues associated with diversity are not yet resolved. Choosing criteria for evaluating diversity is not a straight-forward procedure. Different diversity indices may appear to provide conflicting answers to the question, which community is more diverse?.

Comparisons of communities using single indices of diversity might result in irrelevant conclusions (Hurlbert 1971). An enumeration of species numbers at one scale (Hill 1973), as well as a measurement of spatial patterning, is a more useful measure of biotic heterogeneity (i.e., diversity). A thorough representation of forest stand diversity can thus be obtained by considering overall diversity (stand-scale) as a function of mean within-sampling unit (alpha-scale) and among-sampling unit (beta-scale) components (Wilson and Shmida 1984). Patil and

Taillie (1982) likened this concept to an analysis of variance (ANOVA) decomposition of total sums of squares into within- and among-class sources of variability. A more complete assessment of overall stand-scale diversity may be further made by considering complete abundance vectors as represented by dominance-diversity curves (Whittaker 1965) or proportional diversity profiles (Swindel et al. 1987).

Goals and Objectives

The goal of the research described here was to evaluate the impacts of chemical and mechanical site preparation to determine if, and how, the resultant plant communities differ in composition and diversity. The null hypothesis was that the occurrence and abundance of individual plant species, number of species, and spatial organization of those species were approximately the same following both treatments. The objectives were to: 1) quantify shifts in species composition due to site preparation treatment, 2) determine if differences in site preparation resulted in different overall species-abundance distributions, and alpha- and beta-scale diversities, and 3) within mechanical treatments, examine the influence of windrow proximity on species composition and diversity.

Methods

Study Area Description and History

Selected study sites were part of an industrial private landholding in Levy County, Florida, approximately 15 km west of the town of Otter Creek. The region is known

locally as Gulf Hammock (Vince et al. 1989). Being in excess of 40,000 ha, Gulf Hammock is the largest single expanse of the hydric hammock type (Simons et al. 1989).

Gulf Hammock merges into gulf salt marshes on the west, flatwoods and mesic hammocks on the east, and wet flatwoods that form a matrix for smaller hydric hammocks to the north. Several bald cypress (Taxodium distichum) - tupelo (Nyssa aquatica) swamps run through the area, draining it into Otter Creek, the Waccasassa River, and the salt-marsh interface. Forest products of the Gulf Hammock area had been extensively logged for southern redcedar (Juniperus silicicola) in the late 1800's (Yearty 1959), for cabbage palm (Sabal palmetto) from 1910 to 1945 (Burtchaell 1949), and native loblolly pine (Pinus taeda) during most of this century. Conversion to loblolly pine plantations had taken place on approximately 80% of the hydric hammock in Gulf Hammock between the early 1970s and the late 1980s (Simons et al. 1989).

Study Sites

Four pine plantations that had been site prepared in 1984 were chosen for study. Two of the stands were aerially treated with 3.4 kg/ha hexazinone. The other two stands were cleared using a KG-blade and debris was piled into windrows. All four stands were hand-planted with loblolly pine during the winter of 1984-85.

All available information indicated that these stands were relatively similar in vegetation composition before harvest, and that site preparation treatments were applied without regard to site characteristics (G. Galpin, Georgia-Pacific Corporation; pers. comm.). Judging from adjacent stands, the overstory composition prior to harvest was dominated by live oak (Quercus virginiana), diamond leaf oak (Q. laurifolia), loblolly pine, and cabbage palm. Hornbeam (Carpinus caroliniana) was a common midstory tree.

Soils are poorly drained, shallow, loamy-textured marine sediments, typically with a black organic muck extending to a sandy clay loam at 9 cm. Limestone bedrock is within 30 cm of the surface, frequently extending up to the surface. These soils are classified as a Waccasassa (loamy, siliceous, non-acid, Thermic Lithic Haplaquepts)-Demory (loamy, siliceous, Thermic Lithic Haplaquolls) complex. Sites are subjected to annual flooding and remain inundated for 1 to 3 months of the year, usually in late summer and fall.

Field Sampling

The geometric center of each treated stand was located and a 4 ha (200 X 200 m) sampling area established. Thirty intersections of 10 x 10 m grid-lines were chosen at random for sampling within each stand. A 5-m line transect was established in a random direction at each sampling point. Percent foliar cover for all woody plants along each transect was recorded by species. An expandable rod with an

attached carpenter's level was used to vertically project line interceptions up into the canopy. Occurrence of herbaceous species was noted for each 1 m segment, as was total herbaceous cover. The ratio of the number of 1-m segments along which a herbaceous species occurred was used to create an artificial abundance score (0, 0.2, 0.4, 0.6, 0.8, or 1.0) for each species on a transect. For transects established within the mechanically treated stands, distance was recorded from transect center to the approximate center of the nearest windrow.

Measures of Plant Community Attributes

Diversity measures were calculated using a notation and interpretation developed by Hill (1973). These indices were calculated as:

$N0$ = total number of species;

$$N1 = \text{Exp}[-\Sigma_i\ p_i \ln(p_i)]; \quad [1]$$

$$N2 = 1/\Sigma_i\ p_i^2, \quad [2]$$

where p_i is the proportional abundance (cover) of the ith species. N1 is the exponent of Shannon's index (Shannon and Weaver 1949) and N2 is the inverse of Simpson's index (Simpson 1949). These measures have been recommended because they represent actual units of species numbers (Hill 1973, Ludwig and Reynolds 1988). The conceptual difference in the three numbers N0, N1, and N2 is that they place decreasing importance on species of lesser abundance such that N0 is number of species, N1 is number of "abundant" species, and N2 is the number of "very abundant" species

(Hill 1973). Since percent cover for herbaceous species was not estimated, calculations were restricted to the N0 measurements.

Estimates of overall species diversity (stand diversity) were obtained using a jack-knifing technique to create a series of normally distributed pseudovalues (Zahl 1977). The procedure required repeated calculation of a standard estimate V (the diversity measure), deleting each sample in turn, resulting in $\underline{n}$=30 jack-knife estimates (VJ_i). The pseudovalues (VP_i) were then calculated as

$$VP_i = (\underline{n}V)-[(\underline{n}-1)(VJ_i)]. \quad [3]$$

The best estimate of the diversity measure was then the mean of the pseudovalues (Magurran 1988). These means will hereafter be referred to as $stand_{N0}$, $stand_{N1}$, and $stand_{N2}$ for the three Hill diversity measures N0, N1, and N2, respectively.

Alpha diversity (the number of species within transect samples) was estimated using the mean for each diversity measure from the individual transects (Wilson and Shmida 1984). These means will hereafter be referred to as $alpha_{N0}$, $alpha_{N1}$, and $alpha_{N2}$.

Beta diversity (the amount of turnover in species composition from one transect to another) was estimated using the previously explained jack-knifing procedure [3] for a modification of the beta measure proposed by Whittaker (1960):

$$W\text{-}beta_{NK} = (stand_{NK}/alpha_{NK})-1, \quad [4]$$

where K denotes the specific diversity measure (i.e., K=0, 1, or 2). These means will hereafter be referred to as W-beta$_{N0}$, W-beta$_{N1}$, and W-beta$_{N2}$.

Dissimilarity coefficients (Magurran 1988) were used as another measure of beta diversity. These were calculated for all pairwise comparisons of transect compositions within each stand using modifications of Sorenson's similarity coefficient (Bray and Curtis 1957), with the equation taking the form:

$$\text{dis-beta}_{NK} = 1 - 2_jN/(aN + bN), \qquad [5]$$

Where aN = alpha$_{N0}$ for transect a when K = 0, aN = LN(alpha$_{N1}$) for transect a when K = 1, and N = 1/alpha$_{N2}$ for transect a when K = 2; bN was likewise for transect b; and jN = the number of species found on both transects for alpha$_{N0}$; and jN = the sum of the lower of the two transformations of species proportions prior to summation in [1] and [2] ($p_i LN p_i$ and p_i^2 for alpha$_{N1}$ and alpha$_{N2}$, respectively). These will hereafter be referred to as dis-beta$_{N0}$, dis-beta$_{N1}$, and dis-beta$_{N2}$.

Statistical Analyses

Treatment means were compared using analysis of variance (ANOVA) (general linear models procedure) for a nested design, in which site was nested within treatment (SAS Institute 1985). Two different model specifications were used to test for significant treatment effect; a fixed-effects model using the mean square error for the overall model as the denominator of the F-ratio, and a random-

effects model in which the type III mean square error for site nested within treatment was used.

It was impossible to divide the study area into replicate portions, take pretreatment measurements, and randomly impose manipulations (treatments). The study was, therefore, not fully experimental (Goodall 1970). It was necessary to consider two critical assumptions to make statistical inference: 1) plant communities at pretreatment were similar in composition across all four stands; and 2) site preparation was applied to stands without regard to site characteristics that were determinant of plant community development.

If both assumptions were valid, then site could have been treated as a fixed-effect. If the first assumption was violated, then site would have been considered to be a random-effect. If both assumptions were violated, neither approach would be statistically defensible for testing treatment effects. No evidence was available that would indicate that these assumptions were violated. Furthermore, stands assigned a specific site preparation treatment were not chosen using site criteria considerations (G. Galpin, Georgia-Pacific Corporation, Pers. Comm. and unpublished files). Therefore, evidence indicated that the second assumption was not violated. Without quantitative evidence with which to base a decision concerning similarity of pretreatment compositions, statistical significance under

both model specifications are presented, and discrepancies between the two are noted.

Within the mechanically treated stands, sample transects were arbitrarily divided into three zones depending upon their spatial proximity to a windrow center-line (windrow = <5 m, adjacent = 5-10 m, and inter-windrow= >10 m). ANOVA was used to test for responses in foliar cover and alpha-scale diversity measures. Dis-beta coefficients were compared within and among windrow categories to determine if beta diversity was influenced by windrow distance. Stand was used as a statistical block in the model. Sample sizes were not equal, so means were separated using the Waller-Duncan K-ratio procedure (Waller and Duncan 1969, SAS Institute 1985).

Results

Species Response to Treatment

Under the random-effects model, pepper vine (Ampelopsis arborea), Virginia creeper (Parthenocissus quinquefolia), summer grape (Vitis aestivalis) and muscadine (V. rotundifolia) had significantly higher foliar cover on mechanically treated stands than on herbicide-treated stands (Table 3-1). Foliar cover by cabbage palm and greenbrier (Smilax bona-nox) was significantly greater on hexazinone treatments. Because of variation between the stands within a treatment category, the fixed-effects model indicated significant treatment response for a greater number of species, two of which were notable. Wax-myrtle (Myrica

Table 3-1. Mean foliar cover estimates for woody plant species in loblolly pine (Pinus taeda) plantations established on hydric hammock sites in Levy, County Florida. In 1984, 2 stands were aerially treated with 3.4 kg a.i./ha liquid hexazinone (Velpar-L™); while another 2 stands were mechanically treated (sheared with KG-blade and windrowed). Measurements were taken along 30 5-m transects within each stand during the summer of 1991.

	Foliar cover (%)				
	Hexazinone		Mechanical		
Species[a]	Mean	SE	Mean	SE	P-value[b]
Woody Species	181.80		207.33		
Trees	94.39		100.01		
Acer rubrum	0.06	0.04	1.44	0.77	0.27 **
A. saccharum floridanum	0.14	0.14	0.60	0.45	0.18
Carya aquatica	1.07	1.07	0.07	0.07	0.63
Carpinus caroliniana	6.91	2.28	14.21	2.28	0.48 ***
Carya glabra	.	.	0.07	0.07	0.42
Celtis laevigata	.	.	1.79	1.11	0.31 *
Fraxinus caroliniana	.	.	0.09	0.07	0.42
F. pennsylvanica	.	.	0.58	0.35	0.42
Juniperus silicicola	2.84	1.19	0.25	0.25	0.48 *
Liquidambar styraciflua	7.04	2.42	8.94	2.15	0.44
Magnolia virginica	.	.	0.07	0.07	0.42
Morus rubra	.	.	0.27	0.19	0.42
Nyssa sylvatica	0.58	0.52	0.05	0.05	0.25
Ostrya virginiana	.	.	0.77	0.51	0.42
Persea borbonia	1.15	0.77	0.28	0.28	0.21
Pinus taeda	35.53	3.99	34.68	3.66	0.57
Quercus laurifolia	5.57	1.89	6.15	2.18	0.98
Q. michauxii	0.03	0.03	.	.	0.42
Q. nigra	14.20	2.91	17.26	3.52	0.86
Q. virginiana	2.40	1.01	3.98	1.31	0.32
Sabal palmetto	15.78	2.65	3.57	1.37	0.08 ***
Tilia caroliniana	.	.	0.28	0.28	0.42
Ulmus alata	0.70	0.56	1.04	0.70	0.69
U. americana	.	.	2.15	1.42	0.42
U. crassifolia	0.37	0.29	1.42	0.53	0.38
Shrubs	51.44		46.04		
Aster carolinianus	.	.	0.17	0.17	0.42
Baccharis halimifolia	12.30	2.12	18.32	2.04	0.23 **
Callicarpa americana	1.42	0.62	0.51	0.25	0.75
Cephalanthus occidentalis	0.37	0.28	.	.	0.42
Cornus foemina	2.59	1.11	5.66	1.23	0.15 **
Crataegus sp.	.	.	0.68	0.68	0.42
Cyrilla racemiflora	1.81	1.11	0.43	0.33	0.66
Diospyros virginiana	0.55	0.41	1.05	0.71	0.70
Euonymous americanus	0.05	0.05	.	.	0.42
Eupatorium capillifolium[c]	1.89	0.68	0.25	0.10	0.52 *
Hypericum spp.	1.40	0.48	1.24	0.33	0.65
Ilex cassine	.	.	0.28	0.24	0.42
I. vomitoria	5.09	1.56	3.08	1.01	0.73
Leucothoe racemosa	.	.	0.07	0.07	0.42
Myrica cerifera	19.88	3.11	5.66	1.35	0.61 ***

Table 3-1. Continued.

Species	Foliar cover (%) Hexazinone Mean	SE	Mechanical Mean	SE	P-value[a]
Prunus americana	.	.	0.68	0.68	0.42
Rhus copallina	.	.	0.79	0.40	0.42 *
Rubus betulifolius	2.19	0.76	2.53	0.59	0.56
R. trivialis	.	.	0.07	0.05	0.42
Salix caroliniana	0.18	0.18	2.33	1.52	0.36
Vaccinium arboreum	.	.	0.01	0.01	0.42
Viburnum dentatum	.	.	1.29	0.75	0.31
V. obovatum	1.71	0.66	0.92	0.50	0.66
Vines	35.97		61.28		
Ampelopsis arborea	2.20	0.97	13.61	2.99	<0.0001 ***
Berchemia scandens	0.78	0.40	0.28	0.20	0.55
Bignonia capreolata	0.55	0.26	0.03	0.02	0.01 *
Dioscorea floridana	0.05	0.05	0.07	0.07	0.93
Gelsemium sempervirens	2.39	0.84	0.03	0.03	0.44 ***
Lonicera sempervirens	0.20	0.14	0.10	0.07	0.19
Matelea caroliniensis[c]	0.03	0.03	.	.	0.42
Mikania scandens[c]	0.81	0.27	0.41	0.14	0.80
Parthenocissus quinquefolia	0.71	0.35	3.35	0.80	0.08 ***
Passiflora suberosa[c]	0.53	0.53	.	.	0.42
Smilax bona-nox	13.62	1.66	2.42	0.44	0.03 ***
S. auriculata	0.93	0.41	0.49	0.30	0.57
S. walteri	0.35	0.35	.	.	0.42
S. tamnoides	0.78	0.22	0.07	0.05	0.003 **
Toxicodendron radicans	1.95	0.33	1.98	0.34	0.83
Trachelospermum difforme	0.36	0.21	0.22	0.16	0.48
Vitis aestivalis	4.08	1.62	18.26	2.63	0.03 ***
V. rotundifolia[d]	5.64	2.08	19.63	2.93	0.03 ***
V. vulpina	.	.	0.35	0.22	0.16

[a] Unless stated, taxonomic nomenclature follows Wunderlin (1982).

[b] P-values are for treatment response while site is considered a random-effect, whereas asterisks denote a significant treatment response while site is considered a fixed-effect (*=P<0.05, **=P<0.01, ***=P<0.001). See text for discussion of model interpretation.

[c] Herbaceous perrennials that were considered to be a component of the woody canopy as opposed to the herbaceous ground-layer.

[d] Identification and nomenclature follows Godfrey (1988) for this species.

cerifera) was more prevalent in the hexazinone treatments, while hornbeam was more common within mechanical treatments.

Frequency scores were similar for most herbaceous species (Table 3-2). Under the random-effects model, the only species approaching significance in which differences were substantial was wild petunia (Ruellia caroliniensis). This was a common forb that was approximately twice as abundant on hexazinone treatments.

Considering the fixed-effects model, spike chasmanthium (Chasmanthium laxum) was substantially more frequent on transects within hexazinone treatments. High mean frequency scores for Juncus spp. on the mechanical treatments were due to two transects with frequency scores of 100%. Statistical significance under the fixed-effects model was demonstrated for six other species for which actual differences in mean frequency scores were quite small.

Diversity Response to Treatment

Nineteen woody species occurred in mechanical treatments that did not occur on the hexazinone treatments. Conversely. There were only three species on the hexazinone treatments that did not occur on the mechanical treatments. Thus, species richness at the stand scale ($stand_{N0}$) was greatest following mechanical treatments (Table 3-3). No difference in stand diversity could be detected when relative cover was considered ($stand_{N1}$ and $stand_{N2}$).

Dominance-diversity curves illustrate the similarities in species-abundance relationships for all but the rarest

Table 3-2. Mean frequency scores (see text) for herbaceous plant species in loblolly pine (Pinus taeda) plantations established on hydric hammock sites in Levy County, Florida. In 1984, 2 stands were aerially treated with 3.4 kg a.i./ha liquid hexazinone (Velpar L™); while another 2 stands were mechanically treated (sheared with KG-blade and windrowed). Measurements were taken along 30 5-m transects within each stand during the summer of 1991.

	Frequency score				
	Hexazinone		Mechanical		
Species[a]	Mean	SE	Mean	SE	P-value[b]
Grasses					
Andropogon spp.	0.67	0.47	1.33	0.80	0.70
A. capillipes[c]	.	.	0.33	0.33	0.42
A. glomeratus	29.67	3.34	28.67	4.02	0.93
A. virginicus	.	.	1.00	0.74	0.42
Chasmanthium laxum	28.67	4.47	16.67	3.40	0.36 *
Dichanthelium spp.	4.67	2.04	3.00	1.15	0.67
D. commutatum	47.33	4.09	33.33	3.74	0.37
Digitaria sp.	0.33	0.33	.	.	0.42
Erianthus giganteus	1.33	0.65	0.67	0.47	0.55
Oplismenus setarius	.	.	1.00	0.57	0.10
Panicum anceps	4.00	1.41	8.67	2.39	0.49
P. rigidulum	1.67	1.09	0.67	0.47	0.65
Paspalum sp.	.	.	0.33	0.33	0.42
Tripsacum dactyloides	0.67	0.67	.	.	0.42
Grass-like					
Carex spp.	5.00	1.47	5.33	1.71	0.95
Chromolaena odorata	2.00	1.13	0.33	0.33	0.50
Cyperus spp.	1.00	0.57	3.33	1.18	0.02 *
Juncus spp.	2.67	1.21	11.67	2.48	0.40 ***
Rhynchospora spp.	67.00	3.68	55.67	3.59	0.40 *
Forbs					
Asclepias perennis	.	.	1.00	0.57	0.10
Canna flacida	.	.	0.33	0.33	0.42
Centella asiatica	1.33	0.65	5.00	2.05	0.51
Cirsium sp.	3.67	1.61	0.33	0.33	0.02 *
Conoclinum coelestinum	0.33	0.33	1.33	0.65	0.54
Desmodium sp.	1.33	0.65	.	.	0.42
Dichondra caroliniensis	5.33	1.64	9.33	2.20	0.42
Elytraria caroliniensis	4.00	1.04	4.00	1.14	0.99
Elephantopus nudatus	0.33	0.33	.	.	0.42
Erechtites hieracifolia	1.67	0.86	3.00	1.15	0.45
Eupatorium capillifolium	0.67	0.47	0.67	0.47	0.99
E. compositifolium	0.33	0.33	.	.	0.42
E. perfoliatum	3.33	1.79	0.67	0.47	0.07
Euthamia minor	.	.	0.33	0.33	0.42
Galactia mollis	.	.	0.33	0.33	0.42
Galium spp.	0.33	0.33	0.33	0.33	0.99
Hedyotis uniflora	0.33	0.33	.	.	0.42
Hydrocotyl umbellata	12.00	2.43	16.00	2.51	0.69
Hypericum mutilum	1.67	0.72	.	.	0.42 *
Hyptis alata	5.00	1.75	5.00	2.00	0.99
Lactuca spp.	0.67	0.47	0.33	0.33	0.42

Table 3-2. Continued.

Species	Frequency score				
	Hexazinone		Mechanical		
	Mean	SE	Mean	SE	P-value
Lippia nodiflora	4.00	1.83	1.67	1.37	0.28
Ludwigia maritima	5.00	1.47	7.33	2.07	0.40
Melothria pendula	.	.	4.00	1.04	0.10 ***
Mitreola petiolata	3.33	1.18	7.67	2.11	0.51
Oxalis spp.	0.33	0.33	1.00	0.74	0.60
Pentodon pentandrus	.	.	1.00	0.57	0.42
Physalis arenicola	0.33	0.33	.	.	0.42
Polygonum hydropiperoides	2.67	1.11	6.67	2.16	0.26
Proserpinaca pectinata	0.67	0.67	0.33	0.33	0.71
Rubus sp.	.	.	0.33	0.33	0.42
Ruellia caroliniensis	40.00	4.01	20.33	3.06	0.08 ***
Sagittaria latifolia	.	.	0.67	0.47	0.42
Scutellaria integrifolia	17.00	3.11	11.67	2.48	0.38
Scleria sp.	0.33	0.33	.	.	0.42
Solidago spp.	2.33	0.84	8.33	2.14	0.05 *
Teucrium canadense	.	.	2.33	1.51	0.01
Viola affinis	9.00	1.81	10.33	2.10	0.83
V. lanceolata	2.00	1.13	0.33	0.33	0.50
Xyris sp.	0.33	0.33	.	.	0.42
Ferns					
Asplenium sp.	.	.	0.67	0.47	0.42
Woodwardia virginica	.	.	1.00	0.57	0.42

[a] Unless stated, taxonomic nomenclature follows Wunderlin (1982).

[b] P-values are for treatment response while site is considered a random-effect, whereas asterisks denote a significant treatment response while site is considered a fixed-effect (*=P<0.05, **=P<0.01, ***=P<0.001). See text for discussion of model interpretation.

[c] Synonymous with Andropogon virginicus L. var. glaucus Hackel. (Wunderlin 1982).

Table 3-3. Plant diversity in loblolly pine (Pinus taeda) plantations established on hydric hammock sites in Levy, County Florida. In 1984, 2 stands were aerially treated with 3.4 kg a.i./ha liquid hexazinone (Velpar-L™); while another 2 stands were mechanically treated (sheared with KG-blade and windrowed). Measurements were taken along 30 5-m transects within each stand during the summer of 1991.

	Diversity measure				
	Hexazinone		Mechanical		
$Scale_{LEVEL}$[a]	Mean	SE	Mean	SE	P-value[b]
Woody vegetation					
$Stand_{N0}$	48.17	2.40	64.95	3.13	0.05 ***
$Stand_{N1}$	16.93	1.16	18.93	0.95	0.34
$Stand_{N2}$	11.16	0.98	12.89	0.89	0.60
$alpha_{N0}$	8.85	0.44	11.25	0.35	0.008 ***
$alpha_{N1}$	5.73	0.23	6.99	0.26	0.003 ***
$alpha_{N2}$	4.71	0.21	5.57	0.23	0.002 **
$W\text{-}beta_{N0}$	4.43	0.25	4.78	0.25	0.50
$W\text{-}beta_{N1}$	1.96	0.15	0.71	0.11	0.44
$W\text{-}beta_{N2}$	1.37	0.17	1.31	0.14	0.93
$Dis\text{-}beta_{N0}$	55.67	0.48	54.06	0.44	0.67
$Dis\text{-}beta_{N1}$	60.08	0.52	56.70	0.43	0.46 ***
$Dis\text{-}beta_{N2}$	74.91	0.67	72.99	0.61	0.49 ***
Herbaceous vegetation					
$Stand_{N0}$	46.10	2.77	49.16	2.67	0.68
$Alpha_{N0}$	7.78	0.41	8.45	0.54	0.72
$W\text{-}beta_{N0}$	5.37	0.39	5.19	0.33	0.84
$Dis\text{-}beta_{N0}$	55.00	0.50	63.80	0.50	0.09 ***

[a] Diversity "scale" denotes consideration of overall species abundance (Stand), mean within-transect species abundance (Alpha), cumulative numbers of among-transect species turnovers (W-beta), and mean percent dissimilarity of species compositions between all pairwise comparisons of transects (Dis-beta). Diversity "level" denotes the level of consideration given to the abundance of each species such that N0 considers all species regardless of abundance, whereas N1 and N2 place progressively more weighting upon abundance (percent cover).

[b] P-values are for treatment response while site is considered a random-effect, whereas asterisks denote a significant treatment response while site is considered a fixed-effect (*=$P<0.05$, **=$P<0.01$, ***=$P<0.001$). See text for discussion of model interpretation.

species (Figure 3-1). The point of departure between the two treatments was for those species that had estimated foliar coverages of <0.3% of the entire treatment -- beyond which, more woody species occurred on the mechanical treatments. When cumulative proportions were compared in a diversity profile, the skewed right tail further illustrated this pattern of decreased numbers of quantitatively rare species (Figure 3-2).

The approximate locations of N1 and N2 are indicated in Figure 3-2. At the points of intersection for these measures, the diversity profile was at or near the point of equivalent proportional abundances. This condition indicated that there were no quantitative differences in diversity at those depths of abundance consideration. The points on the axes that corresponded to the $stand_{N1}$ and $stand_{N2}$ positions indicated that these diversity measures accounted for about 80 and 90 percent of the woody cover, respectively.

Alpha-scale diversity was significantly higher on the mechanical treatments at all three levels of abundance consideration (Table 3-3). Not only were there more species along each transect, but the relative abundance for each species was more evenly distributed.

No treatment differences could be demonstrated for beta-scale diversity using Whittaker's (1960) measure (W-beta). Mean $dis\text{-}beta_{N1}$ and $dis\text{-}beta_{N2}$ values were, however, greater on hexazinone treated sites. Statistical

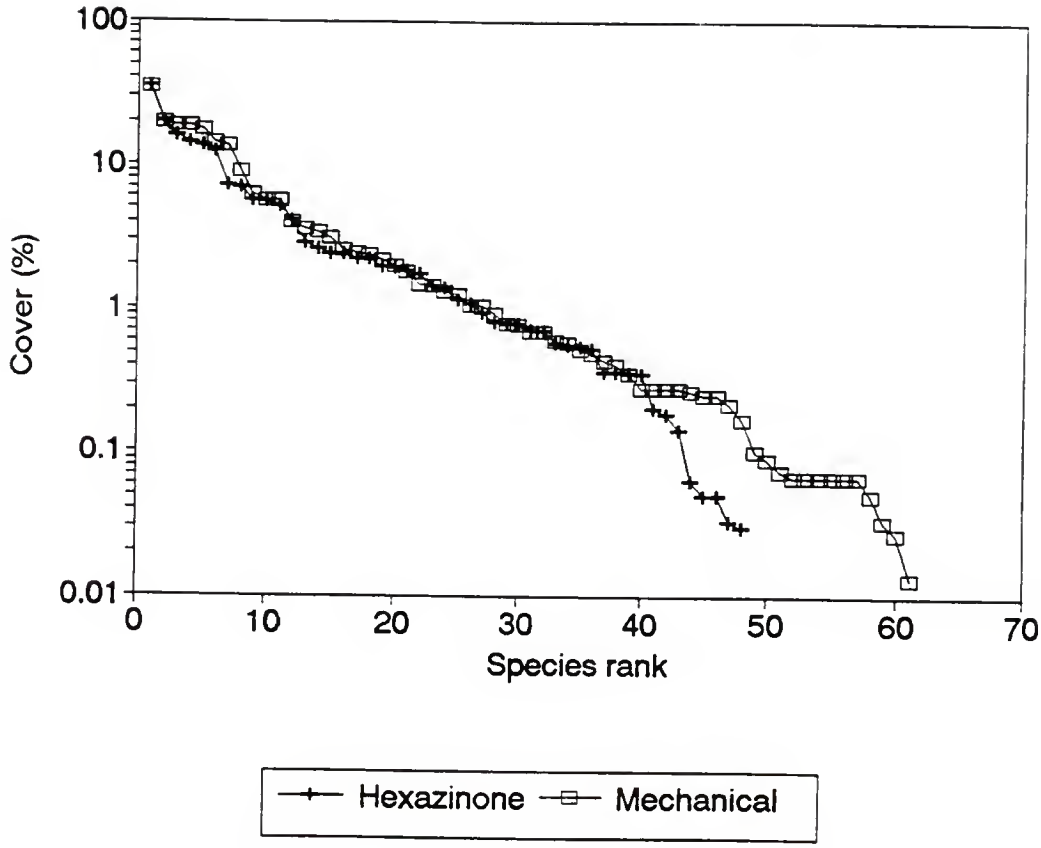

Figure 3-1. Rank abundance plot for woody species found in 7 year-old loblolly pine (Pinus taeda) plantations on hydric hammock sites that were site prepared with hexazinone (3.4 kg/ha) and sheared with a KG-blade and windrowed (mechanical), Levy County, Florida.

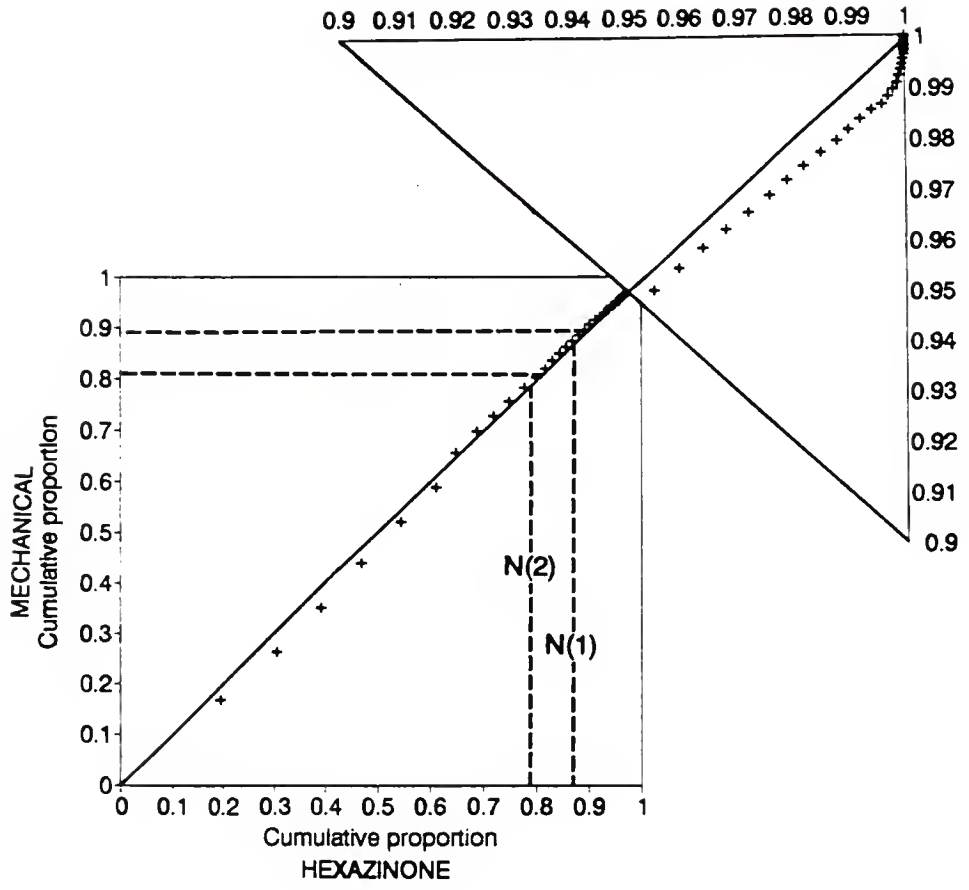

Figure 3-2. Diversity profile (Swindel et al. 1987) comparing proportional abundance of woody species found in 7 year-old loblolly pine (Pinus taeda) plantations on hydric hammock sites that were site prepared with hexazinone (3.4 kg/ha) and sheared with a KG-blade and windrowed (mechanical), Levy County, Florida. N(1) and N(2) denote the intersections of Hill's diversity numbers (Hill 1973) with the respective cumulative proportion axes.

significance could only be detected when the assumptions of the fixed-effects model were accepted.

For herbaceous vegetation, no differences could be demonstrated between site preparation treatments for stand- or alpha-scale diversities (Table 3-3), nor were there any differences in W-beta. Dis-beta, however, was significantly higher on mechanical treatments (fixed-effects model).

Windrow Influences

Differences in foliar cover, in relation to distance from a windrow center, were statistically significant for three woody species, and for total herbaceous cover (Figure 3-3). Muscadine reached its greatest foliar cover on (<5 m) and adjacent (5-10 m) to windrows, being only about one-third as abundant in the inter-windrow area (>10 m) (P=0.002). Loblolly pine cover on windrows was approximately one-half of that elsewhere (P=0.04). Yaupon (Ilex vomitoria) cover was almost nonexistent on windrows, but was substantially greater in the inter-windrow zone (P =0.05). Herbaceous cover in the adjacent and inter-windrow zones was approximately double that of windrows (P=0.002).

Although species compositions changed in relation to windrow proximity, no windrow-related differences were detected in the three measures of alpha-scale diversity for woody species (P=0.40, 0.44, and 0.36 for $alpha_{N0}$, $alpha_{N1}$, and $alpha_{N2}$, respectively). $Alpha_{N0}$ for herbaceous species was 5.1 on windrows, compared to 9.0 and 9.3 for adjacent and inter-windrow zones, respectively (P=0.004).

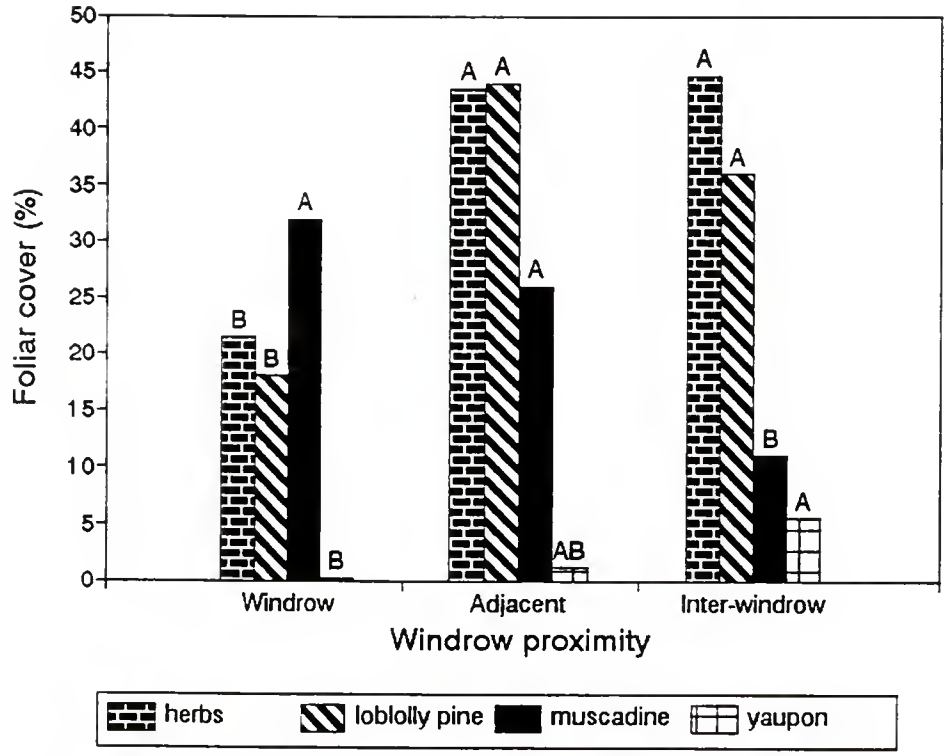

Figure 3-3. Mean herbaceous cover and woody species foliar covers that showed significant response ($P<0.05$) by ANOVA to windrow proximity. Zones were windrow (<5 m), adjacent (5-10 m), and inter-windrow (>10 m). For each species, multiple comparisons were significantly different ($P<0.05$) by Waller-Duncan K-ratio if signified by different letters among windrow distance categories.

Comparisons of beta-scale diversity measures within and across windrow zones indicated that species composition adjacent to windrows was generally more homogenous than elsewhere (Figure 3-4). The greatest contributions to overall beta-scale diversity for woody species resulted from compositional differences among windrow transects, and from the across-zone comparisons of windrow and inter-windrow transects.

For herbaceous species, the beta-scale measures were similarly influenced by windrow proximity. Inter-windrow transects were the most homogenous, followed by those adjacent to windrows. The windrow versus inter-windrow, and windrow versus adjacent comparisons made major contributions to overall beta-scale diversity for herbs.

Discussion

Species Compositions

Loblolly pine was the dominant woody plant in all stands inventoried, and had attained essentially the same mean canopy cover under both treatments. Hexazinone site prepared stands had greater cover by cabbage palm, greenbrier, wax-myrtle and southern redcedar than did mechanically treated stands. When compared with mechanical treatment, hexazinone treatment resulted in greater cover by evergreen tree species. This feature is considered typical of naturally occurring hydric hammock vegetation (Vince et al. 1989, Ewel 1990). Regeneration of cabbage palms is of importance for maintaining typical hydric hammock flora

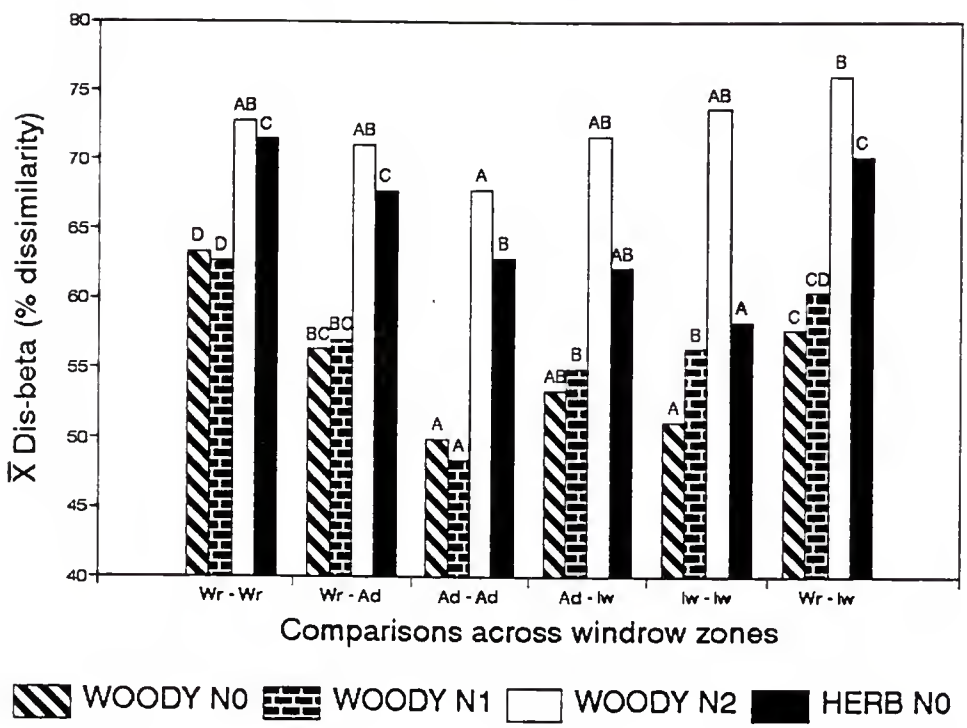

Figure 3-4. Mean dis-beta measures (percent compositional dissimilarity, see text for details) for hydric hammock plant communities as influenced by comparisons within and across windrow zones. Zones were windrow (Wr), adjacent (Ad), and inter-windrow (Iw); at <5, 5-10, and >10 m from windrow centerline, respectively. Mean dis-beta measures differed across windrow zone comparisons ($P<0.05$) if signified by different letters (Waller-Duncan K-ratio used as multiple comparison procedure).

because of its classification as a dominant tree species in >80% of mature hydric hammock stands inventoried by Vince et al. (1989).

On mechanically site prepared stands, deciduous vines of the Vitaceae family predominated and hornbeam cover was higher. While hornbeam is considered to be an abundant understory tree in these systems, summer grape is the only Vitaceae species considered to be an "abundant" hydric hammock species; and then only within the canopies of mature trees (Vince et al. 1989). Woody plant communities in mechanically treated stands were essentially deciduous with the exception of planted loblolly pines.

The abundance of three woody species (loblolly pine, muscadine, and yaupon) within the mechanical treatments varied in relation to distance to the nearest windrow. Loblolly pine was not as abundant directly on windrows as it was elsewhere, because trees were not planted on windrows. The concentration of muscadine on, and adjacent to, windrows very likely resulted from the combination of available propagules and suitable climbing structure from tree tops that were pushed into windrows. Most grapevines were rooted within the nutrient rich windrows (Morris et al. 1983), and extended >10 m to either side of the windrow (Figure 3-3). The prevalence of muscadine on and adjacent to windrows also was noted by Swindel et al. (1986) on a flatwoods Spodosol site. Yaupon might have been overtopped and out-competed in

the areas on and adjacent to windrows, resulting in its preference for areas >10 m from a windrow center.

The fact that occurrences of herbaceous species were so similar suggests that treatments had analogous long-term influences on herbaceous communities. There was, however, a reduction in herbaceous cover associated with windrows. This probably resulted because of increased shading associated with vine cover on the windrow structure.

All 19 species missing from hexazinone treated stands, but were recorded on mechanically treated stands, have been listed by either Vince et al. (1989), Godfrey (1988), or Wunderlin (1982) as being part of the characteristic flora of hydric hammocks. If the conservation of a full spectrum of hydric hammock plants is of concern, then this requires further management attention.

Diversity

Visual inspection and comparisons of dominance-diversity curves (Figure 3-1) can provide insight into community structure not attainable from single-number diversity indices (Hughes 1986). The woody species abundance distribution for both treatments were sigmoidal and approximated a typical log-normal distribution (Whittaker 1977). Some observations have indicated that stressed, polluted, or otherwise disturbed ecosystems result in a shift from the log-normal distribution to a geometric distribution typified by increased dominance and decreased richness (May 1981). The dominance-diversity curves of

these communities exhibited nearly identical dominance when comparing treatments, but the hexazinone treated stands had lower combined species richness. Even though the distributions for dominant species were similar, there were marked differences in species that made up the distribution.

Alpha-scale diversity numbers enumerated mean numbers of species within assemblages, while beta-scale diversity measures enumerated the number of complete assemblage changes (W-beta) or mean compositional dissimilarity among assemblages (dis-beta). The boundary of an assemblage (5-m line) was, albeit, arbitrary. The results, however, did reveal important patterns that probably resulted from differences in site preparation treatment.

Alpha-scale diversity for woody species was highest in the mechanically site prepared stands, regardless of the importance relegated to abundant species. Although W-beta measures did not demonstrate any differences in the community turnover rates, dis-beta measures were higher for N1 and N2 levels of diversity. This suggests that the comparatively lower alpha-scale diversity was compensated for by the uniqueness of individual species assemblages, only when increased importance was placed on abundant species. The lack of any difference in dis-beta$_{N0}$ indicates that the increased stand$_{N0}$ in mechanical treatments was principally a function of an increase in alpha-scale diversity (or in this case, species richness).

Theoretically, alpha-scale diversity is a function of the supply rate of controlling resources (i.e., nutrients, light, water) at specific microsites (transects), while beta-scale diversity is a function of the spatial heterogeneity of resources (Tilman 1982, Shmida and Wilson 1985, Palmer 1991).

Both chemical and intensive mechanical site preparation treatments can suppress or completely eliminate dominant species from the community. So, treatment induced impacts on alpha- and beta-scale diversity may not be strictly due to manipulations of supply rates and spatial heterogeneity of controlling environmental factors. Selective elimination of competition or stimulation of some species may have played an important role. For example, hexazinone probably suppressed vines from the Vitaceae family (Chapter 2), reducing competition for young cabbage palm seedlings and wax-myrtle sprouts. Also, mechanical treatments probably uprooted and eliminated understory cabbage palm, in much the same way that the closely related saw-palmetto (Serenoa repens) is suppressed by mechanical treatment (Tanner et al. 1988). Similar impacts were likely encountered by species of lesser abundance.

Although beta-scale diversity in the hexazinone treatments could have been influenced by spatial variability in herbicide rate, this was not quantified. In the mechanically treated stands, however, dis-beta at all levels of consideration for both woody and herbaceous vegetation

was influenced by distance from the windrows. Thus, a portion of the spatial heterogeneity that was reflected in dis-beta was likely due to the redistribution of topsoil, nutrients, organic matter, and plant propagules that occurs with shearing and windrowing operations (Morris et al. 1981).

The pairwise transect comparisons that resulted in the highest dis-beta measures resulted from those comparisons involving windrow transects, indicating that the species assemblages on windrows were the most unique. Thus, for woody vegetation, not only were mechanically prepared stands apparently more homogenous at the N1 and N2 levels, but a substantial portion of the heterogeneity that did exist at all levels of consideration could be attributed to the construction of windrows. Similarly for herbaceous vegetation, greater dis-beta values for mechanically prepared stands is largely explained by the windrow effect.

Nutrient enrichment of microsites can result in increased dominance and decreased species richness (Tilman 1982:108-114). Swindel et al. (1986) documented that nitrogen, phosphorus, potassium, calcium, and magnesium levels on windrows were >10 times those levels on soils not within windrows. This likely contributed to a decrease in $alpha_{NO}$ for herbaceous vegetation <5 m from windrow centers. Intense growing season shade provided by the tangle of vines associated with windrows probably contributed further to

herbaceous diversity reductions by suppressing shade intolerant species.

Summary and Recommendations

When compared with shearing and windrowing, use of hexazinone for site preparation of hydric hammock sites in the plantation conversion process results in a loss of some woody species. The dominance distribution was not influenced by treatment, although the plants that dominated the composition (except for planted pines) were different in species, form, and deciduous versus evergreen composition. Hexazinone treatment resulted in a shift toward evergreen trees, shrubs and vines, while deciduous vines dominated the mechanically site prepared stands.

Hexazinone treatments, although resulting in decreased species diversity at particular microsites, resulted in more unique woody species assemblages (i.e., greater spatial heterogeneity) than did mechanical treatments, especially when the effects of windrows were taken into account. Numbers of species that were common were not influenced by treatment.

The impacts of these two treatments on herbaceous composition was not different, except that microsites within 5 m of a windrow center typically had fewer species numbers and reduced foliar cover. There were no treatment differences in overall species numbers ($stand_{NO}$), mean species numbers at microsites ($alpha_{NO}$), or species turnover rate ($W\text{-}beta_{NO}$). The dissimilarities of herbaceous species

assemblages among microsites (dis-beta$_{NO}$), however, was higher on mechanically treated sites. Again, this was largely a function of the uniqueness of microsites on or near windrows.

These data indicate that hexazinone application is the more desireable site preparation technique when considering the needs of a wide variety of vertebrate wildlife species. One of the most important considerations is maintenance of dominant evergreen species. These species are most important for provision of winter food and cover for those species that may use adjacent deciduous ecosystems during the remainder of the year (Simons et al. 1989). Evergreen hammock communities also supply an important winter foraging base for a large and diverse community of over-wintering, frugivorous birds (Skeate 1987). Hexazinone treated stands were also more spatially heterogenous. This attribute has been related to density and diversity of forest bird communities in a variety of temperate ecosystems (Roth 1976, Freemark and Merriam 1986).

Large live oaks, cabbage palms and other unmerchantable trees remained standing on hexazinone treated stands, providing potential snag habitat for cavity using birds (Dickson and Conner 1985) for several years. In addition, logging debris remains scattered across a hexazinone treated site (as opposed to being piled into windrows), thus favoring reptile and amphibian communities (Enge and Marion 1986).

Applications of hexazinone can probably be altered to provide for the conservation of quantitatively rare woody plant species. Important areas should be excluded from application. For example, observations indicate that small (<0.2 ha) circular depressions at Gulf Hammock contain high densities of pop ash (Fraxinus caroliniana) and green ash (F. pennsylvanica). These were species that were absent from herbicide-treated stands and rare on mechanically-treated stands. Observations were that most other scarce woody species also occurred in small aggregations as opposed to scattered individuals.

It is recommended that hydric hammock sites destined for conversion to pine plantation be inventoried prior to harvest and again before site preparation. All micro-sites that contain concentrations of relatively scarce woody species should be noted, and avoided during subsequent treatment. Attention should be given especially to those species that did not occur on hexazinone treated stands in the present study (Table 3-1). Furthermore, "skips" that remain when helicopter application strips do not overlap should be retained. In the past, these have been retreated. These narrow (<15 m) untreated strips would allow for reduced probabilities of extirpation of locally scarce woody species. Finally, as other herbicides and mechanical treatments are considered for use on hydric hammock sites, their relative impacts on plant composition and diversity should be compared to those of the present study.

CHAPTER 4
USE OF HEXAZINONE FOR UNDERSTORY RESTORATION OF A SUCCESSIONALLY ADVANCED XERIC SANDHILL

Introduction

The undulating sand ridges of central peninsular Florida were once dominated by a near continuous assemblage of open longleaf pine (*Pinus palustris*) overstories, with a ground cover dominated by pineland threeawn, otherwise known as wiregrass (*Aristida stricta*) (Nash 1895). On many sites there also was a thin midstory of turkey oaks (*Quercus laevis*) and/or bluejack oaks (*Q. incana*) (Myers and White 1987). The characteristic understories of these pinelands were maintained by recurrent summer ground fires at a frequency of 3 to 4 years (Chapman 1932).

Longleaf pines exhibit a fire resistant grass-stage and have thick, fire-insulating bark when mature (Wahlenberg 1946), as does the bark of large diameter turkey oaks. Wiregrass quickly resprouts and sets an inflorescence following a growing-season burn (Myers 1990). Furthermore, both pine needles and wiregrass provide a constant fuel source for frequent ground fires, thereby encouraging continued fire (Clewell 1989). Although evergreen oaks and other more mesic hardwoods will grow on these sites, they

are generally excluded when natural fire frequencies are allowed.

Following exclusion from fire, xeric sandhills tend to succeed to either a mesic or a xeric hardwood forest (Monk 1960, Veno 1976, Daubenmire 1990), depending upon the character of the seed supply (Myers 1985). These stands are characterized by increased midstory shading, heavy litter accumulation, and a thinning of the herbaceous ground cover (Veno 1976, Givens et al. 1981). When high-intensity fires occur in these successionally-advanced stands, site occupancy may change to a "scrub", dominated by sand pine (Pinus clausa) in the overstory and a thick midstory of xeric evergreen oaks (Quercus myrtifolia, Q. geminata, and Q. chapmannii) (Myers 1985). Shrubs common to the sand pine scrub communities have been shown to further inhibit growth and reproduction of the former sandhill vegetation through allelopathic leachates (Richardson and Williamson 1988).

Numerous vertebrate species are dependant upon the perpetuation of longleaf pine communities characteristic of the more frequently burned xeric sandhills. These include the federally endangered red-cockaded woodpecker (Picoides borealis), the state-listed (species of special concern) Florida gopher tortoise (Gopherus polyphemus) and Sherman's fox squirrel (Sciurus niger shermani), and the state-listed (endangered) Florida mouse (Podomys floridanus) (Myers 1990). The entire longleaf pine ecosystem is considered to be endangered due to fire exclusion and clearing for pine

plantations, agriculture and human development (Means and Grow 1985).

Management efforts have recently concentrated on the reintroduction of summer fires to xeric sandhills systems in an effort to return the vegetation to a fire maintained savanna. Prescribed fire has most commonly been used as the restoration tool -- but only when fine ground fuels in the form of wiregrass have remained abundant (Clewell 1989, Myers 1990). Sites that have been excluded from fire for 40 to 50 years develop an oak midstory that results in such a sparse cover of wiregrass that ground fires cannot be readily ignited. Other management alternatives must therefore be developed as part of the restoration process.

One method of facilitating an initial reclamation burn is the use of a selective herbicide to suppress midstory oaks while releasing wiregrass growth in the understory. Hexazinone is one such herbicide that has been utilized, with some success, for this purpose (Duever 1989).

Previous studies have shown that southern yellow pines resist the effects of hexazinone while most oak species have been noted to be quite susceptible (Gonzales 1983, Griswold et al. 1984, Zutter et al., 1988). Differential susceptibilities to hexazinone also have been noted for several other hardwood species (Zutter and Zedaker 1988). Operational trials have indicated that wiregrass also is a hexazinone-resistant species (Duever 1989, Outcalt in review, R. Mulholland, Pers. Comm.). These responses

suggest that hexazinone may play an important role in xeric sandhill restoration efforts.

Several questions still remain regarding the use of hexazinone for sandhill plant community restoration. Adequate efficacy results for the selective control of small diameter oaks are not available. Also, there is concern for the survival of other understory plants of lesser abundance, that are nevertheless important members of the sandhill plant community. The overall goal of this research was to quantify the initial hexazinone rate-response of trees and understory vegetation in a successionally-advanced (fire excluded) sandhill community. The specific objectives were to: 1) determine oak stem mortalities and shrub canopy reductions as a response to relatively low (≤1.68 kg/ha) application rates of liquid hexazinone (VELPAR-L™); and 2) document the subsequent release and/or inhibition of plant species in the understory, especially wiregrass.

Methods

Study Area

The experiment was installed on a sandhill site along the western edge of Wekiwa Springs State Park in Orange County, Florida, approximately 3 km east of the town of Apopka (28° 40'N, 81° 30'W). Soils on the site are well-drained, deep, acidic sands of the Lakeland-Eustis-Norfolk association (hyperthermic, coated Typic Quartzipsamments). Aerial photographs from the 1950's show the area as a relatively open longleaf pine savanna, typical of the

sandhill vegetation once common to the sandy ridges of central Florida. Fire control and exclusion was a park policy until the 1980's. Park records indicate that this site had not been burned for approximately 40 years prior to the initiation of this study.

Although an overstory of scattered longleaf pines still existed on the site, the ground cover was sparse and clumps of wiregrass were isolated and suppressed by litter accumulation. A dense layer of midstory vegetation had developed, and was dominated by a mixture of sand-live oak (Q. geminata), turkey oak, laurel oak (Q. hemisphaerica), myrtle oak (Q. myrtifolia), and sand post oak (Q. margaretta).

Treatments

Efficacy of hexazinone in forest soils across the southern U.S. is negatively correlated with soil pH and percent organic matter, and positively correlated with percent sand (Minogue et al. 1988). Soils of the sandhills typically contain very little organic matter (<1%), are relatively low in pH, and contain >90% sand; low rates of hexazinone can effectively control target species. It was previously observed that the effects of application rates >1.68 kg a.i./ha on a xeric sandhill invaded by evergreen oaks (observed oak kill nearly 100%) was greater than that desired. Because part of the management goal for restoration was to retain larger oaks (≥14 cm dbh), the maximum rate for testing was set at 1.68 kg a.i./ha. On 28

April 1990 a liquid formulation of hexazinone (Velpar-L™) was applied at three rates (0.42, 0.84, and 1.68 kg a.i./ha) to 0.04-ha plots (20 X 20 m). Hexazinone was applied with a single back-pack mounted Solo™ spotgun in a 1 X 1 m square grid pattern. Appropriate concentrations of the compound were used for each treatment rate, so that the volume of liquid applied at each grid location was the same. Treatments were replicated three times in a randomized complete block design, resulting in a total of 12 plots, including 1 control plot (no herbicide) per block. A 5-m untreated buffer was maintained between each designated treatment plot. The experiment was blocked according to plant species composition and midstory woody plant densities.

Plant Measurements

All measurements were conducted prior to treatment and then again at one year post-treatment. Living oak trees (≥2 cm diameter at 1.5 m) within a 0.02-ha subplot (14 X 14 m) in each treatment plot were marked with paint and measured for diameter. Basal area of each wiregrass clump within a 25 m^2 subplot was determined by measuring right-angle diameters at ground line using a caliper.

To correlate basal area with dry weight, a sample of 120 (40 per block) wiregrass clumps were harvested from the 5 m plot buffers and the 3 m boundary zones. Dead leaf material was removed and each harvested plant was oven-dried at 68°C for 72 hrs and then weighed to the nearest 0.05 g.

Foliar cover by vascular plant species in the understory (<1.5 m) was measured to the nearest 1-cm along three, permanently-monumented, 5-m line transects randomly located within each measurement plot. Species identifications followed Wunderlin (1982).

Data Analyses

Because the study design and objectives fell within the definition of a Class I study (Borders and Shiver 1989), response to the quantitative nature of herbicide rate was the main interest (Mize and Schulz 1985, Borders and Shiver 1989). Expressed as a proportion, percent change from pretreatment to post-treatment was, therefore, the variable of interest for statistical analyses.

A predictive model for estimating both pre- and post-treatment biomass of wiregrass using subplot basal area measurements was developed using simple linear regression. Variance was stabilized and the relationship linearized with log transformations on both axes.

Proportional oak mortality, proportional change for wiregrass biomass and cover, understory oak cover, understory cover of other woody plants, grass cover, and forb cover were all analyzed using analysis of variance (General Linear Models procedure) for a randomized complete block design (SAS Institute 1985). Proportional oak mortality was transformed using an arcsine square-root function to stabilize variance. Diameter classes (4-cm) were considered as an additional model term. Each observed

mortality rate was weighted by the number of trees within the observation (plot). Wiregrass and grass proportions required log transformation to stabilize the variance. Model sums of squares were partitioned to yield comparisons of mean response across all hexazinone treatments versus the control, and to model the nature of the response (e.g., linear, quadratic, and/or lack of fit).

Two-tailed T-tests were used to test the null hypothesis that mean diameters of hexazinone-killed oaks were not different from those of the entire population. These tests were conducted for each rate X species combination using the oaks from all three replications of a rate as the test population.

Representatives of all species did not occur on all plots (with the exception of wiregrass). Therefore, comparisons of pre- and post-treatment cover values for some species were made without regard to statistical variance. Since the cover values were derived from both pre- and post-treatment measurements along permanent transects, such comparisons do have validity (see Conde et al. 1986 for an example of this approach).

Results

Oak Mortality

Prior to treatment, mean density of living oak trees was 2045 stems/ha, with 29, 29, 25, and 17 percent of the stems being in the 2-6, 6-10, 10-14, and 14-18 cm diameter classes, respectively. No oak mortalities occurred on

control plots, so only mortalities from treatment plots were entered into ANOVA so as to avoid a bias of the contrasts.

Proportional oak mortality responded in a linear fashion to increases in hexazinone rate (Table 4-1). Mortality increased as diameter decreased. Oaks in the largest diameter class did not experience mortalities.

Significant diameter responses could only be demonstrated for sand-live oak (Table 4-2). Mean diameters of sand-live oaks killed by hexazinone treatments were 3- to 4- cm less than those of the entire population. Sample sizes were low for all species except sand-live oak. This precluded the detection of diameter responses in other species.

Wiregrass Response

The regression equation used to estimate biomass of individual wiregrass plants was:

$$Exp^{DW} = 0.57 + Exp^{BA}(0.59); \quad [1]$$

where DW=Dry weight (gm), and BA=Basal area (cm^2) (R^2=0.84, $P < 0.0001$) (see Figure 4-1). Neither the slope nor the intercept was significantly influenced by time of sampling (pre- vs. post-treatment), so the same equation was used to estimate both pre- and post-treatment biomass.

Proportional change in estimated wiregrass biomass showed a significant treatment response (rate contrast in Table 4-3). This response, however, was not consistent across all treatment rates (Hexazinone vs. Control), and was best described as a higher order polynomial.

Table 4-1. Mean oak (Quercus spp.) mortality following hexazinone applications (1 year post-treatment) on xeric sandhill sites at Wekiwa Springs State Park, Orange County, Florida.

Hexazinone rate (kg a.i./ha)	Diameter (cm)	Mortality (proportion)
0.42	2-6	0.19
	6-10	0.26
	10-14	0.10
	14-18	0.00
0.84	2-6	0.32
	6-10	0.61
	10-14	0.10
	14-18	0.00
1.64	2-6	0.52
	6-10	0.54
	10-14	0.48
	14-18	0.00

Contrasts	P-values
Rate	0.015
Linear	0.009
Lack of fit	0.141
Diameter	<0.001
Linear	<0.001
Quadratic	0.425
Lack of Fit	0.110
Rate X Diameter	0.250

Table 4-2. Means (M) and standard errors (SE) for oak (*Quercus* spp.) diameters at 1.5 m, and numbers of individuals (n) at pretreatment (PRE) and for mortalities (KILL) following hexazinone applications (one year post-treatment) on xeric sandhill sites at Wekiwa Springs State Park, Orange County, Florida.

Species		Hexazinone Rate (kg a.i./ha) 0.42 PRE	0.42 KILL	0.84 PRE	0.84 KILL	1.68 PRE	1.68 KILL
Sand-live oak	M	10.2	6.2**[a]	10.7	7.7**	11.9	9.0**
Q. geminata	SE	(0.5)	(0.3)	(0.5)	(0.5)	(0.5)	(0.5)
	n	72	8	85	25	55	11
Turkey oak		7.8	9.4	6.6	7.1	5.2	6.6
Q. laevis		(1.0)	(1.0)	(0.6)	(0.5)	(0.6)	(0.7)
		14	6	18	14	17	14
Laural oak		6.5	3.8	7.0	3.0	4.8	4.1
Q. hemisphaerica		(1.0)	(1.2)	(1.0)	.	(0.4)	(0.4)
		15	2	9	1	17	11
Sand post oak		5.4	.	5.4	.	5.5	5.0
Q. margaretta		(0.5)	.	(1.7)	.	(0.8)	.
		12	0	3	0	4	1
Bluejack oak		6.5	.	.	.	4.3	3.0
Q. incana		.	.	.	.	(1.3)	.
		1	0	0	0	2	1
Myrtle oak		.	.	2.9	3.1	3.2	3.8
Q. myrtifolia		.	.	(0.1)	.	(0.2)	(0.3)
		0	0	4	1	7	6
Water oak		3.2	.	.	.	.	.
Q. nigra		.	.	.	.	.	.
		1	0	0	0	0	0
ALL OAKS		8.8	7.1*	9.4	7.3**	8.6	6.1**
		(0.4)	(0.6)	(0.4)	(0.4)	(0.5)	(0.4)
		115	16	119	41	102	44

[a] Mean diameters followed by asterisks are significantly different from pretreatment diameters by two-tailed T-test (* = $P<0.05$ and ** = $P<0.01$)

$Exp^{Dry\ Weight} = 0.57 + Exp^{Basal\ Area}$

$R^2 = 0.84$ $\quad$ $P<0.0001$

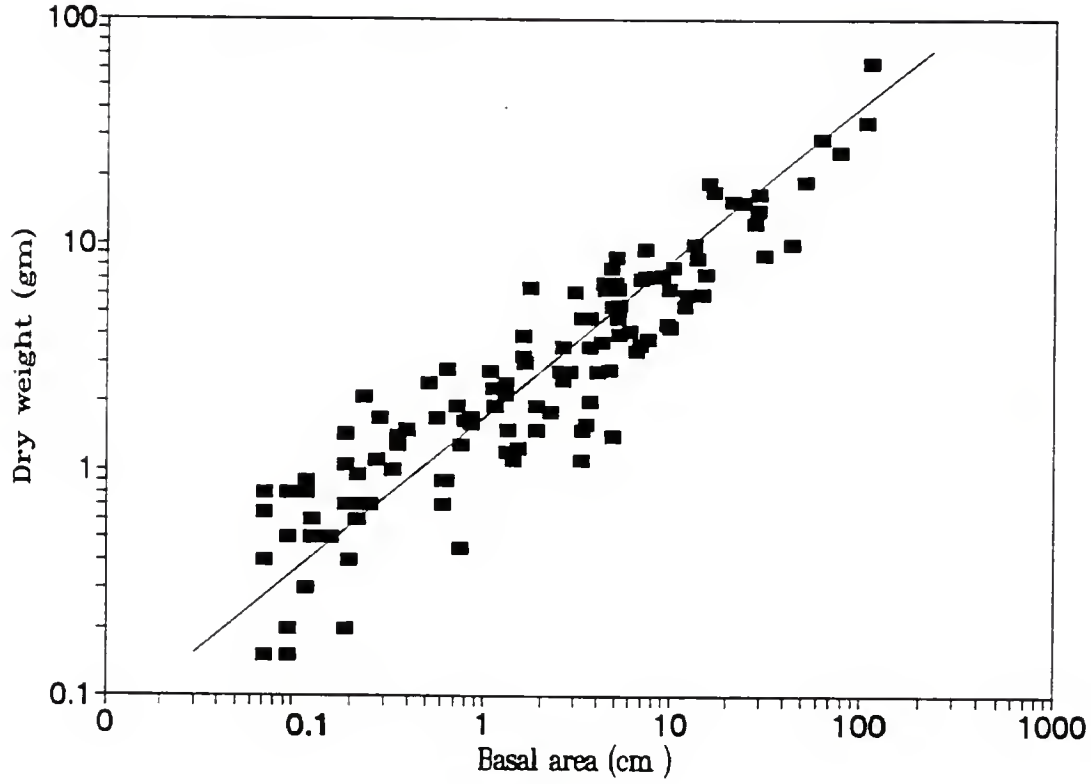

Figure 4-1. Regression line for dry weight of wiregrass (Aristida stricta) as a function of the basal area of individual wiregrass clumps.

Table 4-3. Proportional change in estimated biomass and foliar cover of wiregrass (Aristida stricta) following hexazinone applications (one year post-treatment) on xeric sandhill sites at Wekiwa Springs State Park, Orange County, Florida.

Hexazinone rate (kg a.i./ha)	Estimated biomass	Foliar cover
Control	-0.23	-0.26
0.42	-0.42	+1.21
0.84	+0.49	+1.22
1.68	-0.15	+4.03
Contrasts	P-values	
Hexazinone vs. Control	0.181	0.026
Rate	0.022	0.100
Linear	0.229	0.036
Quadratic	0.038	0.213
Lack of fit	0.014	0.213

Proportional change in wiregrass cover was significantly higher across hexazinone treatments than on the control plots (Table 4-3). Although overall model significance was marginal (Rate in Table 4-3), positive wiregrass cover responses were significantly and linearly related to increases in hexazinone rates (Table 4-3).

Understory Response

Changes in grass and oak cover in the understory were significant across all treatment rates and responded in a linear fashion; oak cover declined and grass cover increased in response to increasing hexazinone rate (Table 4-4). Understory oak cover was not changed on the control plots, while it tended to decrease on treatment plots (Table 4-5). Sand-live oak experienced a slight increase at 1.68 kg/ha apparently due to root suckering of stressed individuals in the midstory.

Saw-palmetto (Serenoa repens) did not occur on control plots, but on treatment plots this species experienced a substantial (35-69%) increase (Table 4-5). Cabbage palm (Sabal palmetto) did occur on a control plot, however, and it experienced an increase (84%) there. Longleaf pine (Pinus palustris) seedlings increased dramatically (535%) on two plots with the lowest treatment rate.

Increases in wiregrass cover on treatment plots are illustrated in Table 4-5. At 1.67 kg/ha, Dicanthelium spp., foxtail grasses (Setaria spp.), and Paspalum spp. all increased or invaded following treatment. Forb cover

Table 4-4. Mean proportional changes[a] in foliar cover for four form classes of understory (<1.5m) vegetation following hexazinone applications (one year post-treatment) on xeric sandhill sites at Wekiwa Springs State Park, Orange County, Florida.

Hexazinone rate (kg a.i./ha)	Oak shrubs	Other woody	Grasses	Forbs
Control	+0.05	+1.06	-0.09	+3.63
0.42	-0.25	+4.11	+0.96	+2.55
0.84	-0.48	-0.03	+2.08	+0.66
1.68	-0.50	+0.15	+4.63	+0.82
Contrasts	P-values			
Hexazinone vs Control	0.022	0.868	0.035	0.254
Rate	0.074	0.384	0.125	0.407
Linear	0.026	0.405	0.045	0.160
Quadratic	0.136	0.722	0.164	0.523
Lack of fit	0.842	0.152	0.499	0.481

[a] Expressed as proportional increase (+) or decrease (-) relative to pretreatment.

Table 4-5. Percent foliar cover for all understory (<1.5 m) plant species at pretreatment (PRE) and one year after (POST) hexazinone applications on xeric sandhill sites at Wekiwa Springs State Park, Orange County, Florida.

	Control		Hexazinone rate (kg a.i./ha) 0.42		0.84		1.68	
	PRE	POST	PRE	POST	PRE	POST	PRE	POST
TOTAL WOODY	30.04	35.33	19.16	22.22	22.49	17.13	28.80	17.07
Total *Quercus* spp.	18.84	19.60	12.27	9.49	15.64	8.09	25.84	14.47
Q. geminata	1.04	1.64	4.16	3.47	0.49	0.07	0.71	1.80
Q. hemisphaerica	1.02	1.33	4.98	3.53	3.53	3.36	5.87	1.67
Q. laevis	1.44	0.78	.	.	1.44	.	4.82	3.78
Q. myrtifolia	10.73	10.67	1.69	1.27	9.13	3.56	9.84	5.07
Q. nigra	0.22	0.27	0.22	.	.	0.22	1.96	.
Q. pumila	.	0.42	.	.	.	0.33	.	.
Q. margaretta	4.38	4.49	1.22	1.22	1.04	0.22	2.64	1.96
Q. virginiana	.	.	.	.	.	0.33	.	0.20
Total other woody	11.20	15.73	6.89	12.73	6.84	9.04	2.96	2.60
Diospyros virginiana	.	0.11	.	.	.	.	1.42	0.20
Gaylussacia nana	.	.	0.09	.	.	.	.	.
Licania michauxii	0.20	0.73	.	0.04	0.33	0.09	.	.
Myrica cerifera	1.49	1.89	.	.	0.38	.	.	.
Opuntia humifusa	0.49	.	.	.	.	.	.	.
Pinus palustris	.	.	0.51	3.24	0.38	0.27	0.11	0.04
Sabal palmetto	2.38	4.40	.	0.07	.	.	.	.
Serenoa repens	.	.	5.24	7.16	5.51	7.42	0.62	1.67
Smilax spp.	0.24	0.27	0.22	.	0.24	0.16	0.67	0.18
Vaccineum arboreum	.	0.04	.	.	.	.	.	.
V. corymbosum	.	.	0.09	1.11	.	.	.	.
V. myrsinites	2.33	3.38	0.33	0.67	.	.	.	.
V. stamineum	2.82	2.82	0.40	0.44	.	1.11	.	.
Vitis munsoniana	1.24	2.09	.	.	.	.	.	.
Yucca filamentosa	.	.	.	.	.	.	0.13	0.51
TOTAL HERBS	5.87	11.89	10.31	19.91	13.18	24.36	7.36	18.91
Total grass	4.18	4.62	8.89	15.51	9.69	17.42	2.38	10.98
Andropogon spp.		.	.	.	0.44	.	.	.
A. virginicus	0.02	0.78	.	0.02	.	.	.	0.18
Aristida stricta	3.29	3.47	7.36	14.02	9.49	15.67	1.42	6.80
A. purpurascens	.	.	.	0.11	.	0.04	0.31	.
Eragrostis spp.	.	0.33	0.07	.	.	0.62	0.13	0.18
Dichanthelium spp.	.	0.04	.	0.24	.	0.56	0.16	1.98
Paspalum notatum	.	.	.	.	.	.	.	0.18
Paspalum spp.	.	.	.	.	.	.	.	0.53
Setaria spp.	.	.	.	.	.	.	.	1.13
Sporobolis junceus	0.31	.	1.47	0.67	0.20	0.53	0.07	.
Stipa avanacioides	0.56	.	.	.	.	.	0.29	.

Table 4-5. -- Continued.

	Control		Hexazinone rate (kg a.i./ha) 0.42		0.84		1.68	
	PRE	POST	PRE	POST	PRE	POST	PRE	POST
Total forbs	1.69	7.27	1.42	4.40	3.49	6.93	4.98	7.93
Acalypha gracilens	.	.	.	0.04	.	.	.	.
Agalinus sp.	.	0.47	.	0.07	.	.	.	.
Carphephorus corymbosum	.	.	.	0.13	.	.	.	.
Centrosema virginianum	.	0.80	0.20	0.07	.	0.16	0.18	0.96
Chapmannia floridana	.	0.80	0.07	0.33	0.60	0.36	0.04	0.64
Croton argyranthemus	0.11	0.11	0.07	0.18	0.27	.	.	.
Crotalaria rotundifolia	.	.	.	.	.	.	.	0.62
Cyperus retrorsus	.	0.11	.	.	.	.	.	.
Elephantopus nudatus	.	0.62	.	0.44	0.29	0.78	0.76	1.56
Erechtites hieracifolia	.	.	.	.	.	0.11	.	.
Eriogonum tomentosum	.	.	.	0.27	.	.	.	.
Eupatorium sp.	.	0.20	.	.	.	.	.	.
Galactia elliottii	1.04	3.09	0.53	1.11	0.82	1.89	0.73	2.38
G. volubilis	.	.	.	.	.	.	0.09	.
Galium sp.	.	.	.	.	.	.	.	0.11
Hieracium gronovii	.	.	.	.	0.02	.	.	.
Liatris sp.	.	.	.	0.09	.	.	.	.
Pityopsis graminifolia	.	.	0.56	0.38	0.02	.	0.80	0.04
Pteridium aquilinum	0.44	0.78	.	0.33	0.60	0.73	2.18	1.29
Pterocaulon virgatum	.	0.11	.	.	.	1.31	.	.
Rhynchosia difformis	.	0.11	.	.	.	.	.	.
R. reniformis	.	.	.	.	.	.	0.07	0.07
Rhynchospora sp.	0.09	.	.	0.07	0.87	1.44	.	0.22
Scleria sp.	.	.	.	.	.	0.16	.	.
Silphium compositum	.	0.07	.	.	.	.	.	.
Solidago sp.	.	.	.	.	.	.	0.13	.
Tephrosia sp.	.	.	.	0.89	.	.	.	0.04

increased on all plots, mostly as a result of an increase in cover by the legumes milk pea (Galactia elliottii), butterfly pea (Centrosema virginianum), and alicia (Chapmannia floridana) (Table 4-5). No consistent treatment response could be determined for the forb community.

Discussion

Hexazinone was found to be successful at controlling understory and smaller-diameter midstory oaks, resulting in a substantial positive response of the grass community. Similar responses to hexazinone have been found in the post oak savannahs of central Texas (Scifres 1982).

The failure to detect statistically significant changes in the forb community and in the non-oak woody category was likely due to confounding introduced by differential hexazinone susceptibilities of species within those categories. Sampling intensities were insufficient to detect changes in all species within all plots. Furthermore, plant distributions were not uniform across all plots. So, it would be incorrect to conclude that there were no treatment differences in the forb, or non-oak woody categories.

Proportional changes in wiregrass biomass estimates were lower in the 1.68 kg/ha treatment, but cover levels showed a linear increase. By chance, wiregrass clumps in the biomass subplots may have been directly contacted with the herbicide. The higher concentrations of hexazinone in the mixture used for 1.68 kg a.i./ha treatments were

probably enough to cause some foliar kill. Although the uptake of triazine herbicides is primarily through the roots, they do exhibit limited foliar penetration (Esser et al. 1975), resulting in localized top-kill (Ashton and Crafts 1973). At hexazinone rates ≤3.4 kg/ha, this top-kill is temporary and wiregrass recovers after the second post-treatment growing season (Chapter 2). Foliar cover measures might not have detected the top-kill of part of a wiregrass clump, especially if other live wiregrass overlapped the deadened spot. Thus, foliar cover measures may not be as influenced by limited top-kill as were biomass estimates.

Larger diameter oaks (>14 cm) were not killed by rates of hexazinone used in this study. This is desirable from a management (sandhills restoration) perspective since some larger diameter oaks are a component of longleaf pine savannahs on xeric sandhill sites (Myers 1985). These results do suggest, however, that it was mainly sand-live oak that exhibited tolerance in the larger diameter classes following treatment. Sand-live oak is an evergreen oak, and is more typical of scrub or xeric hardwood vegetation.

The apparent ability of saw-palmetto to tolerate these rates of hexazinone is of little consequence for utilizing hexazinone for sandhill restoration efforts. Saw-palmetto is considered to be a component of scrub and xeric hardwood habitats (Myers 1990) as opposed to fire maintained xeric sandhills (Daubenmire 1990).

The appearance, and/or increase of several early successional grasses (Dichanthelium spp., foxtail grasses, and paspalums) following 1.68 kg a.i./ha treatment suggests a release of more site resources than could be immediately exploited by the resident ground cover species. The appearance of bahiagrass, an invasive non-native species, is particularly undesirable.

Forb cover increased during the year, regardless of treatment. But the fact that forb cover, especially for the three common native legume species, did not significantly decrease following any of the herbicide treatments is favorable.

Sampling intensities were not great enough to justify computation of diversity measures. However, there were no distinct eradications of herbaceous species following treatment. Occurrences of non-oak woody species did not seem to decline either. This is supported by Zutter and Zedaker's (1988) conclusions that the differences in woody plant communities were small following rates of 1.2 to 1.5 kg a.i./ha.

These results suggest that hexazinone may be used as a restorative tool in anticipation of a series of prescribed fires. Hexazinone released wiregrass and reduced mid- and understory oak without detectable reductions of the other woody and herbaceous components. In order to make precise recommendations concerning the use of hexazinone for oak control, wiregrass release, and subsequent sandhill

restoration, additional experiments of this type are suggested. Timing may influence the susceptibility for certain species, and grid size may influence the probabilities of root zone contact for oak species. Neither of these potential determinants were incorporated into the present study. So, installation of larger experiments in a Rate X Time X Grid-size factorial is recommended.

CHAPTER 5
SYNTHESIS AND SUMMARY

Hexazinone site preparation alters existing plant species composition in the short-term (Chapter 2). Treatment-related changes in composition, diversity, and species-abundance distributions were most pronounced on a xeric sandhill site and least pronounced on a hydric hammock site. On a mesic flatwoods site, responses tended to be intermediate between those of xeric sandhill and hydric hammock sites. These results were from short-term studies but their implications for long-term changes in the plant communities (i.e., divergent successional pathways) become apparent upon consideration of known successional patterns.

A convincing argument can be made that plant community changes as a product of site preparation on a xeric sandhill site have greater probabilities of resulting in long-term shifts in successional development than they would on a hydric hammock site. On sites with low productivity potentials (e.g., xeric sandhill), the pace of succession is expected to be relatively slow. Initial establishments are generally those that allocate more of their resources to roots (Tilman 1988). Once established, they occupy the site for relatively long periods, reproduction being primarily by vegetative means (Grimes 1979). When these stress-

tolerators are removed from the community, reestablishment is expected to be slow. Ruderal species then tend to invade the site (Grimes 1979).

Upon initiation of succession on a site with high productivity potentials (e.g., hydric hammock), early occupants are competitive species with rapid growth rates and most of their resources are allocated to shoots and leaves (Tilman 1988). These species tend to modify the environment such that species typical of later succession are favored (Connell and Slatyer 1977). In the absence of additional disturbance, longer-lived woody species, having advantage of cumulative growth, replace the short-lived species and eventually dominate the community.

The plant communities that existed on the xeric sandhill and hydric hammock sites respectively fit these two scenarios well. Given differences in adaptive strategies of the plants occupying sites at the opposite ends of the edaphic (productivity) gradient, a plant mortality caused by hexazinone on a xeric sandhill site should influence long-term plant community dynamics greater than a mortality on a hydric hammock, or even a mesic flatwoods site. Results presented in Chapter 3 now become somewhat relevant to the extension of those of Chapter 2. On hydric hammock sites, hexazinone treatment resulted in lower overall woody species richness, lower alpha-scale diversity and higher beta-scale diversity -- 7 years after treatment, when compared with an

alternative site preparation treatment (shearing and windrowing).

The obvious question is whether these results are comparable to those of an experiment wherein there was incorporated an untreated site as a control. It is unlikely that a mechanically site prepared stand could result in occurrence of considerably more woody species than an untreated site. So, the absence of 19 woody species from hexazinone treated stands that occurred on mechanically treated stands suggests that hexazinone treatment at 3.4 kg/ha resulted in reduced woody species numbers.

Given these results it becomes reasonable to hypothesize that the short-term changes in plant community dynamics that result from hexazinone site preparation are manifest in noticeable long-term shifts in plant community development. Following hexazinone site preparation, divergence of the plant communities on the xeric sandhill site is expected to be of greater magnitude and of longer duration than on more mesic or hydric sites.

If the physiological activities of hexazinone were non-selective, plant community recovery would simply be dependant upon the forces of secondary succession. The abilities of some plants to tolerate rates of hexazinone that effectively control all competitors makes predictions of plant community response difficult. Those tolerant species that are immediately able to exploit new resources and capture site dominance (e.g., Carolina jessamine, and

gallberry) are potentially the largest source of unpredictable results. Those species are expected to greatly influence the developmental trajectory of those communities within which they have become dominant.

The same plant adaptations that make xeric sandhill communities particularly susceptible to long-term reductions in herbaceous diversity may allow for herbaceous understories to be restored using hexazinone in a different manner. Following fire exclusion, wiregrass and associated stress-tolerant herb species are able to persist under the developing canopy of midstory shrubs for indefinite periods (Clewell 1989). Upon release, these plants are able to recover and, if summer fire is reintroduced, they will bloom and sexually reproduce. Results of Chapter 4 confirm that application of low rates of hexazinone in a grid pattern releases wiregrass from suppression by midstory oaks. Negative impacts on herbaceous vegetation was negligible, probably due to concentrated spot application.

In summary, plant community response to hexazinone is a function of application rate interacting with edaphic factors, adaptive strategies of resident plants, and the presence-absence of hexazinone tolerant species. The impacts on plant diversity are different among sites, with an apparent trend being realized across a generalized moisture-stress gradient. On hydric hammock sites, hexazinone site preparation resulted in a shift toward evergreen trees, shrubs and vines, while deciduous vines

dominated on mechanically site prepared stands. These results, along with those indicating greater spatial heterogeneity following hexazinone site preparation, indicate that hexazinone site preparation favors regeneration of important functional attributes of hydric hammock sites -- especially for providing habitats for over-wintering birds. However, hexazinone site preparation probably results in long-term elimination of some woody species from the site.

APPENDIX
MEAN FOLIAR COVER FOR EACH SPECIES BY
TREATMENT RATE FOR THREE STUDY SITES OF CHAPTER 2
PT=PRETREATMENT, Y1=FIRST GROWING SEASON, Y2=SECOND GROWING SEASON

Xeric Sandhill.

Species	Time	Hexazinone rate (kg/ha) 0.0	1.7	3.4	6.8
		---- Foliar cover (%) ---			
TREES AND SHRUBS					
Asimina incarna (Bartr.) Exell	PT	0.47	1.52	0.82	0.34
	Y1	0.23	1.23	1.21	0.71
	Y2	0.04	1.00	0.50	0.33
Asimina longifolia Kral	PT	0.50	0.04	0.05	0.15
	Y1	.	.	0.06	.
	Y2	0.19	0.15	.	.
Crataegus sp. L.	PT	.	.	0.27	0.53
	Y1	.	.	0.08	0.29
	Y2	.	.	.	.
Dalea pinnata (Walt. ex J. F. Gmel.) Barneby	PT	.	.	.	.
	Y1	0.81	.	.	.
	Y2	.	.	.	.
Diospyros virginiana L.	PT	0.81	1.51	0.94	0.29
	Y1	0.19	0.23	0.06	.
	Y2	0.50	0.29	.	.
Garberia heterophylla (Bartr.) Merr. & Harp.	PT	0.01	0.05	0.19	.
	Y1	.	0.04	.	.
	Y2	0.38	1.11	0.49	0.38
Gaylussacia nana (A. Gray) Small	PT	.	.	.	.
	Y1	.	.	0.02	.
	Y2	.	.	.	.
Gordonia lasianthus (L.) Ellis	PT	0.05	.	.	.
	Y1	.	.	.	.
	Y2	.	.	.	.
Hypericum spp. L.	PT	.	0.05	.	.
	Y1	0.15	.	.	.
	Y2	0.29	.	.	.

APPENDIX--continued.
Xeric Sandhill.

Species	Time	Hexazinone rate (kg/ha) 0.0	1.7	3.4	6.8
		---- Foliar cover (%) ---			
Kalmia hirsuta Walt.	PT	.	.	.	.
	Y1	.	.	.	.
	Y2	.	0.02	.	0.17
Licania michauxii Prance	PT	0.08	.	.	.
	Y1	0.10	.	.	.
	Y2	0.19	.	.	.
Liquidambar styraciflua L.	PT	.	.	.	.
	Y1	.	.	.	.
	Y2	.	.	0.21	.
Magnolia grandiflora L.	PT	.	.	0.10	.
	Y1	.	.	.	.
	Y2	.	.	.	.
Myrica cerifera L.	PT	0.46	2.19	1.25	0.36
	Y1	0.33	0.83	0.25	.
	Y2	1.08	1.71	0.06	.
Prunus serotina Ehrh.	PT	.	.	.	0.24
	Y1	.	.	.	.
	Y2	0.29	.	0.04	0.17
Prunus umbellata Ell.	PT	.	.	0.28	0.62
	Y1	0.06	.	0.04	.
	Y2	0.15	.	0.58	.
Quercus geminata Small	PT	1.69	3.59	0.27	0.58
	Y1	3.10	0.10	.	.
	Y2	4.27	0.29	.	.
Quercus hemisphaerica Bartr.	PT	5.37	2.77	1.65	4.37
	Y1	6.06	0.17	.	.
	Y2	7.85	0.02	.	.
Quercus incana Bartr.	PT	5.18	5.22	10.37	8.07
	Y1	5.04	0.23	.	.
	Y2	9.67	0.23	0.04	.
Quercus laevis Walt.	PT	1.65	1.38	0.20	1.95
	Y1	1.46	.	.	.
	Y2	2.21	0.21	.	.
Quercus nigra L.	PT	0.47	0.39	1.95	0.56
	Y1	0.42	.	.	.
	Y2	0.58	0.21	.	.
Quercus stellata Wang.	PT	.	.	0.68	.
	Y1	.	.	.	.
	Y2	0.04	.	.	.

APPENDIX--continued.
Xeric Sandhill.

Species	Time	Hexazinone rate (kg/ha) 0.0	1.7	3.4	6.8
		---- Foliar cover (%) ---			
Quercus virginiana Mill.	PT	0.66	0.36	0.10	1.29
	Y1	0.19	0.04	.	.
	Y2	2.60	.	0.04	.
Rhus copallina L.	PT	1.30	1.36	2.74	2.33
	Y1	2.17	0.46	.	.
	Y2	6.10	4.04	0.90	0.08
Sassafras albidum (Nutt.) Nees	PT	.	0.55	0.05	0.18
	Y1	.	0.19	.	.
	Y2	.	0.25	.	.
Vaccinium arboreum Marsh.	PT	0.61	2.40	1.28	2.65
	Y1	0.83	2.90	1.44	2.50
	Y2	0.71	2.69	1.77	1.79
Vaccinium myrsinites Lam.	PT	.	0.31	0.10	0.09
	Y1	.	0.21	.	.
	Y2	.	0.35	.	0.13
Vaccinium stamineum L.	PT	4.06	3.50	1.90	5.70
	Y1	3.04	2.92	1.27	4.40
	Y2	2.88	2.38	1.69	5.10
Yucca filamentosa L.	PT	.	.	.	.
	Y1	.	.	0.13	.
	Y2	.	.	0.10	.
Zamia pumila L.	PT	.	0.23	0.13	.
	Y1	0.15	0.54	0.06	0.13
	Y2	0.25	0.54	0.21	0.38
WOODY VINES					
Gelemium sempervirens (L.) J. St. Hil.	PT	0.50	2.95	3.26	0.55
	Y1	0.65	14.25	3.92	0.13
	Y2	1.21	26.35	12.25	1.08
Rubus cuneifolius Pursh	PT	0.77	0.73	1.59	0.07
	Y1	1.48	0.29	.	.
	Y2	1.02	0.38	0.44	.
Smilax spp. L.	PT	0.03	0.10	0.02	.
	Y1	0.08	0.31	.	.
	Y2	0.13	0.29	.	.
Smilax bona-nox L.	PT	0.03	0.39	.	0.01
	Y1	0.21	0.21	.	.
	Y2	0.19	1.23	.	0.02
Smilax glauca Walt.	PT	0.25	0.33	0.36	0.21
	Y1	0.40	0.35	0.04	0.02
	Y2	0.31	1.02	0.58	0.08

APPENDIX--continued.
Xeric Sandhill.

Species	Time	Hexazinone rate (kg/ha) 0.0	1.7	3.4	6.8
		---- Foliar cover (%) ---			
Vitis aestivalis Michx.	PT	0.23	.	.	.
	Y1	0.54	.	.	.
	Y2	0.25	.	.	.
Vitis rotundifolia Michx.	PT	0.03	1.07	.	.
	Y1	.	0.08	.	.
	Y2	.	.	.	.
GRASS-LIKES					
Cyperus retrorsus Chapm.	PT	0.04	0.17	0.15	0.03
	Y1	.	0.07	.	.
	Y2	.	0.96	.	.
Rhynchospora megalocarpa A. Gray	PT	.	.	.	.
	Y1	0.39	.	.	.
	Y2	.	.	.	.
GRASSES					
Andropogon spp. L.	PT	0.57	.	0.19	0.06
	Y1	2.01	0.03	.	.
	Y2	0.57	0.97	.	0.14
Andropogon capillipes Nash.	PT	.	1.01	2.61	0.49
	Y1	.	.	.	.
	Y2	.	.	.	.
Andropogon virginicus L.	PT	1.77	.	0.57	2.15
	Y1	1.18	.	.	.
	Y2	0.76	0.67	1.14	1.47
Aristida purpurascens Poir.	PT	.	.	.	.
	Y1	0.17	.	.	.
	Y2	0.65	.	0.04	.
Aristida stricta Michx.	PT	0.25	0.28	1.64	2.64
	Y1	0.69	0.56	0.42	0.69
	Y2	1.11	1.14	3.42	0.29
Cenchrus sp. L.	PT	.	.	.	.
	Y1	.	.	.	.
	Y2	0.21	.	.	0.14
Dichanthelium spp. (Hitchc. & Chase) Gould	PT	9.96	15.73	11.52	12.50
	Y1	17.15	0.90	.	.
	Y2	14.78	4.99	9.00	4.29
Digitaria villosa (Walt.) Pers.	PT	.	.	.	.
	Y1	.	.	.	.
	Y2	0.63	2.86	1.49	1.43

APPENDIX--continued.
Xeric Sandhill.

Species	Time	Hexazinone rate (kg/ha) 0.0	1.7	3.4	6.8
		---- Foliar cover (%) ---			
Eragrostis spp. N. M. von Wolf	PT	.	0.47	0.47	0.22
	Y1	0.63	.	.	.
	Y2	0.99	0.67	1.00	2.26
Panicum anceps Michx.	PT	1.73	.	.	0.38
	Y1	1.53	.	.	.
	Y2	0.53	.	.	.
Paspalum spp. L.	PT	.	.	0.52	.
	Y1	.	.	.	.
	Y2	.	.	.	0.69
Paspalum setaceum Michx.	PT	2.08	1.01	2.56	.
	Y1	4.15	0.14	.	.
	Y2	2.96	2.82	8.85	6.01
Schizachyrium scoparium (Michx.) Nash	PT	.	1.23	.	.
	Y1	0.53	1.60	.	.
	Y2	1.26	3.21	.	.
Setaria spp. Beauv.	PT	.	0.13	0.10	.
	Y1	0.04	.	.	.
	Y2	.	1.49	1.56	0.17
Sorghastrum secundum (Ell.) Nash	PT	0.92	2.26	.	.
	Y1	1.81	1.04	.	.
	Y2	1.85	0.92	.	.
Triplasis spp. Beauv.	PT	.	.	.	.
	Y1	0.35	.	0.14	.
	Y2	.	.	.	.
FERNS					
Pteridium aquilinum L. Kuhn.	PT	2.38	5.19	1.80	3.76
	Y1	0.42	5.61	.	0.28
	Y2	0.13	1.14	.	.
FORBS					
Acalypha gracilens A. Gray	PT	.	.	.	.
	Y1	0.03	.	.	.
	Y2	.	0.79	0.94	0.25
Ambrosia artemisiifolia L.	PT	.	.	.	.
	Y1	.	.	.	.
	Y2	0.17	.	0.29	.
Anthaenantia villosa (Michx.) Beauv.	PT	.	.	.	.
	Y1	.	.	.	.
	Y2	.	0.10	.	.

APPENDIX--continued.
Xeric Sandhill.

Species	Time	Hexazinone rate (kg/ha) 0.0	1.7	3.4	6.8
		---- Foliar cover (%) ---			
Asclepias tuberosa L.	PT	.	.	.	.
	Y1	0.04	.	.	.
	Y2	.	.	.	.
Aster walteri Alex.	PT	0.13	.	.	.
	Y1	0.17	.	.	.
	Y2	.	.	.	.
Balduina angustifolia (Pursh) Robins.	PT	.	.	.	.
	Y1	0.11	.	.	.
	Y2	0.81	0.79	.	.
Baptisia lecontei Torr. & Gray	PT	0.25	.	0.31	0.14
	Y1	.	.	.	.
	Y2	.	.	0.13	.
Carphephorus corymbosus (Nutt.) Torr. & Gray	PT	.	.	.	.
	Y1	.	.	.	.
	Y2	.	.	0.08	.
Cassia fasciculata Michx.	PT	0.27	0.08	0.36	0.16
	Y1	.	.	.	.
	Y2	1.58	7.98	10.58	8.40
Centrosema virginianum (L.) Benth.	PT	.	.	.	.
	Y1	.	.	.	.
	Y2	.	0.28	.	.
Clitoria mariana L.	PT	.	.	.	.
	Y1	.	.	.	.
	Y2	.	0.11	.	.
Cnidoscolus stimulosus (Michx.) Engelm. & Gray	PT	0.18	0.13	0.11	.
	Y1	.	.	.	.
	Y2	.	0.07	0.10	.
Conyza canadensis (L.) Cronq.	PT	0.06	.	0.15	0.40
	Y1	0.36	.	.	.
	Y2	.	.	0.36	.
Crotalaria rotundifolia (Walt.) Gmel.	PT	.	.	.	.
	Y1	0.14	.	.	.
	Y2	0.07	.	.	.
Croton argyranthemus Michx.	PT	.	0.06	.	.
	Y1	.	.	.	.
	Y2	.	.	0.21	.
Croton glandulosus L.	PT	.	0.21	0.14	0.21
	Y1	.	.	.	.
	Y2	0.29	0.36	0.39	0.42

APPENDIX--continued.
Xeric Sandhill.

Species	Time	Hexazinone rate (kg/ha) 0.0	1.7	3.4	6.8
		---- Foliar cover (%) ---			
Crotonopsis linearis Michx.	PT	1.12	1.17	1.27	1.17
	Y1	5.80	4.57	.	.
	Y2	1.97	9.40	15.93	24.81
Desmodium nudiflorum (L.) DC.	PT	0.06	0.73	.	0.79
	Y1	0.06	0.07	.	.
	Y2	.	.	.	.
Desmodium tenuifolium Torr. & Gray	PT	.	.	.	.
	Y1	.	.	.	.
	Y2	0.08	.	.	.
Diodia teres Walt.	PT	.	.	.	.
	Y1	0.42	.	.	.
	Y2	.	0.53	0.49	.
Elephantopus elatus Bertol.	PT	0.29	.	0.60	0.51
	Y1	1.40	0.13	.	.
	Y2	1.99	.	.	.
Eriogonum tomentosum Michx.	PT	0.35	.	0.38	.
	Y1	0.72	.	.	.
	Y2	1.00	.	.	0.18
Eryngium aromaticum Baldw. ex Ell.	PT	.	0.19	0.08	.
	Y1	0.60	.	.	.
	Y2	1.18	0.57	.	.
Eupatorium sp. L.	PT	.	.	.	.
	Y1	.	.	.	.
	Y2	0.64	0.11	0.18	.
Eupatorium capillifolium (Lam.) Small	PT	.	.	.	.
	Y1	.	.	.	.
	Y2	.	0.25	.	0.25
Eupatorium compositifolium Walt.	PT	0.48	0.76	.	1.30
	Y1	1.98	.	.	.
	Y2	2.00	1.65	1.04	4.75
Euphorbia sp. L.	PT	.	.	0.10	0.08
	Y1	.	.	.	.
	Y2	.	.	0.01	.
Euthamia minor (Michx.) Greene	PT	.	.	.	.
	Y1	2.68	.	0.07	.
	Y2	1.40	.	1.44	.
Galactia elliottii Nutt.	PT	.	0.15	.	0.18
	Y1	.	.	.	.
	Y2	1.50	0.68	.	.

APPENDIX--continued.
Xeric Sandhill.

Species	Time	Hexazinone rate (kg/ha) 0.0	1.7	3.4	6.8
		---- Foliar cover (%) ---			
Galactia regularis (L.) BSP.	PT	.	0.04	1.15	0.63
	Y1	0.75	0.03	.	.
	Y2	1.14	0.39	0.06	.
Galactia volobulis (L.) Britt.	PT	.	.	.	.
	Y1	.	.	.	.
	Y2	0.14	.	.	0.03
Gnaphalium purpureum L.	PT	.	0.10	.	.
	Y1	.	.	.	.
	Y2	0.35	.	.	.
Hedyotis procumbens (J.F. Gmel.) Fosberg	PT	0.06	.	.	.
	Y1	0.07	.	.	.
	Y2	0.14	0.14	.	0.25
Helianthemum carolinianum (Walt.) Michx.	PT	.	.	.	.
	Y1	.	.	.	.
	Y2	.	0.46	.	.
Helianthemum corymbosum Michx.	PT	0.03	0.18	.	0.05
	Y1	0.17	.	.	.
	Y2	0.38	0.06	.	0.19
Hieracium gronovii L.	PT	.	.	.	0.00
	Y1	0.07	.	.	.
	Y2	.	.	.	.
Hypericum gentianoides L. BSP.	PT	.	.	.	.
	Y1	.	.	.	.
	Y2	.	0.27	0.98	0.21
Hypoxis juncea J. E. Smith	PT	.	.	.	.
	Y1	.	.	.	.
	Y2	0.03	.	0.03	.
Lactuca sp. L.	PT	.	.	.	.
	Y1	.	.	.	.
	Y2	0.10	.	.	.
Lechea sp. L.	PT	.	.	.	.
	Y1	.	.	.	.
	Y2	0.43	.	.	.
Liatris spp. Schreber.	PT	0.97	0.75	1.81	1.11
	Y1	0.96	0.21	.	.
	Y2	0.82	1.75	0.58	1.18
Ludwigia sp. L.	PT	.	.	.	.
	Y1	.	0.21	.	.
	Y2	.	.	.	.

APPENDIX--continued.
Xeric Sandhill.

Species	Time	Hexazinone rate (kg/ha) 0.0	1.7	3.4	6.8
		---- Foliar cover (%) ---			
Phyotolacca americana L.	PT	.	.	.	.
	Y1	.	.	.	.
	Y2	.	.	0.35	.
Piriqueta caroliniana (Walt.) Urban	PT	.	.	.	.
	Y1	0.14	0.11	.	.
	Y2	.	.	.	.
Pityopsis graminifolia (Michx.) Nutt.	PT	0.31	.	.	.
	Y1	0.21	.	.	.
	Y2	0.14	.	.	.
Polygonella gracilis (Nutt.) Meisn.	PT	0.36	0.65	0.10	0.71
	Y1	0.37	.	.	.
	Y2	0.11	0.01	.	0.04
Pterocaulaon virgatum (L.) DC.	PT	.	.	.	.
	Y1	.	0.21	.	.
	Y2	.	.	.	.
Rhynchosia difformis (Ell.) DC.	PT	.	.	.	.
	Y1	.	.	.	.
	Y2	0.04	0.08	.	.
Rhynchosia reniformis DC.	PT	0.03	0.07	.	0.10
	Y1	0.49	0.15	0.02	.
	Y2	.	.	.	.
Scleria sp. Berg.	PT	.	.	.	.
	Y1	.	.	.	.
	Y2	0.01	0.03	.	.
Silphium compositum Michx.	PT	.	.	.	0.22
	Y1	.	.	.	.
	Y2	.	.	.	.
Solidago spp. L.	PT	.	.	.	.
	Y1	.	.	.	.
	Y2	0.04	0.50	.	.
Stillingia sylvatica L.	PT	0.49	.	0.36	0.31
	Y1	0.18	.	.	0.14
	Y2	0.22	.	0.25	.
Tephrosia virginiana (L.) Pers.	PT	0.07	1.82	0.06	.
	Y1	1.08	0.56	.	.
	Y2	0.49	1.44	.	0.14
Tragia urens L.	PT	.	0.26	.	.
	Y1	.	0.07	0.14	.
	Y2	0.46	0.04	0.03	0.44

APPENDIX--continued.
Xeric Sandhill.

Species	Time	Hexazinone rate (kg/ha) 0.0	1.7	3.4	6.8
		---- Foliar cover (%) ---			
Trichostema dichotomum L.	PT	.	.	.	.
	Y1	.	.	.	.
	Y2	.	0.54	.	.
Viola sp. L.	PT	.	.	.	.
	Y1	.	.	.	.
	Y2	.	.	0.01	.

APPENDIX--continued.
Mesic Flatwoods.

Species	Time	Hexazinone rate (kg/ha) 0.0	1.7	3.4	6.8
		---- Foliar cover (%) ---			
TREES AND SHRUBS					
Acer rubrum L.	PT	.	.	0.01	.
	Y1	.	0.02	.	.
	Y2	.	.	.	.
Asimina longifolia Kral	PT	.	.	.	.
	Y1	.	0.06	.	.
	Y2	.	.	.	.
Baccharis halimifolia L.	PT	.	.	.	.
	Y1	.	.	.	.
	Y2	.	0.02	.	.
Callicarpa americana L.	PT	.	.	.	.
	Y1	0.04	0.06	0.08	.
	Y2	0.21	0.27	0.69	0.50
Diospyros virginiana L.	PT	0.93	0.06	.	0.01
	Y1	0.83	0.29	.	.
	Y2	1.00	0.21	.	.
Gaylussacia nana (A. Gray) Small	PT	0.03	.	0.03	.
	Y1	.	.	0.08	.
	Y2	0.08	.	0.21	.
Gordonia lasianthus (L.) Ellis	PT	.	0.06	.	.
	Y1	.	.	.	.
	Y2	.	.	.	.
Hypericum spp. L.	PT	.	0.03	.	.
	Y1	0.19	0.19	.	.
	Y2	2.44	1.53	1.26	2.60
Hypericum fasciculatum Lam.	PT	.	.	.	0.01
	Y1	.	0.58	.	.
	Y2	.	0.23	0.04	0.17
Ilex glabra (L.) A. Gray	PT	0.12	0.38	0.89	2.51
	Y1	0.35	2.54	4.00	1.69
	Y2	0.46	4.10	14.69	5.21
Liquidambar styraciflua L.	PT	0.79	0.78	4.43	3.09
	Y1	9.77	0.44	0.27	.
	Y2	14.96	1.54	0.69	.
Myrica cerifera L.	PT	2.43	1.58	2.14	2.16
	Y1	3.46	1.63	0.60	0.31
	Y2	5.33	1.69	1.15	0.02

APPENDIX--continued.
Mesic Flatwoods.

Species	Time	Hexazinone rate (kg/ha) 0.0	1.7	3.4	6.8
		---- Foliar cover (%) ---			
Persia borbonia (L.) Spreng.	PT	.	.	.	.
	Y1	.	.	.	.
	Y2	.	.	.	0.04
Quercus hemisphaerica Bartr.	PT	1.40	0.09	0.38	0.61
	Y1	2.69	0.17	.	.
	Y2	3.15	0.23	.	.
Quercus nigra L.	PT	2.00	4.74	1.60	1.43
	Y1	5.77	2.15	1.02	0.27
	Y2	8.54	3.08	1.98	0.88
Quercus virginiana Mill.	PT	1.28	3.26	0.43	2.39
	Y1	1.58	0.83	0.31	.
	Y2	3.77	1.71	0.02	.
Rhus copallina L.	PT	.	.	.	.
	Y1	.	.	.	.
	Y2	.	0.04	.	.
Serenoa repens (Bartr.) Small	PT	.	0.31	.	.
	Y1	.	0.48	.	.
	Y2	.	0.77	.	.
Vaccinium arboreum Marsh.	PT	.	.	0.03	.
	Y1	.	.	0.04	.
	Y2	.	.	0.10	.
Vaccinium myrsinites Lam.	PT	.	0.21	0.05	.
	Y1	.	0.50	0.04	.
	Y2	.	0.98	0.19	.
Vaccinium stamineum L.	PT	0.02	0.06	.	.
	Y1	.	.	.	.
	Y2	.	.	.	.
WOODY VINES					
Gelsemium sempervirens (L.) J. St. Hil.	PT	0.05	0.08	0.26	0.64
	Y1	0.92	1.42	1.90	1.85
	Y2	1.35	4.94	4.17	2.29
Rubus betulifolius Small	PT	.	.	.	.
	Y1	.	.	.	.
	Y2	0.31	.	.	.
Rubus cuneifolius Pursh.	PT	0.03	.	0.03	0.10
	Y1	0.90	.	.	.
	Y2	4.08	0.02	0.13	0.38

APPENDIX--continued.
Mesic Flatwoods.

Species	Time	Hexazinone rate (kg/ha) 0.0	1.7	3.4	6.8
		---- Foliar cover (%) ---			
Smilax spp. L.	PT	0.21	.	.	.
	Y1	.	.	.	.
	Y2	0.08	.	.	.
Smilax bona-nox L.	PT	0.19	0.02	0.05	0.14
	Y1	0.56	.	0.19	0.06
	Y2	0.56	0.15	0.25	0.08
Smilax glauca Walt.	PT	0.08	0.01	0.16	.
	Y1	0.33	.	0.29	.
	Y2	0.17	0.02	0.06	.
Vitis rotundifolia Michx.	PT	0.05	.	0.32	0.01
	Y1	0.73	.	.	.
	Y2	0.08	0.02	0.06	.
GRASS-LIKES					
Cyperus spp. L.	PT	.	.	.	.
	Y1	.	.	.	.
	Y2	.	.	.	0.01
Cyperus retrorsus Chapm.	PT	2.18	2.18	2.51	0.76
	Y1	4.65	2.19	0.62	0.03
	Y2	0.14	0.68	0.50	2.04
Juncus spp. L.	PT	.	.	.	.
	Y1	.	.	.	.
	Y2	.	.	0.24	1.17
GRASSES					
Amphicarpum muhlenbergianum (Schult.) Hitchc	PT	.	0.08	.	.
	Y1	.	.	.	.
	Y2	.	0.49	3.68	.
Andropogon spp. L.	PT	.	.	0.07	.
	Y1	.	.	.	.
	Y2	.	.	.	.
Andropogon capillipes Nash	PT	0.85	.	.	0.19
	Y1	0.88	0.35	.	.
	Y2	3.32	2.75	12.56	21.32
Andropogon glomeratus (Walt.) BSP.	PT	.	.	.	.
	Y1	.	.	.	.
	Y2	.	.	.	0.49
Andropogon virginicus L.	PT	0.50	0.13	0.29	.
	Y1	0.36	1.64	.	.
	Y2	1.88	5.06	3.13	3.49

APPENDIX--continued.
Mesic Flatwoods.

Species	Time	Hexazinone rate (kg/ha) 0.0	1.7	3.4	6.8
		---- Foliar cover (%) ---			
Aristida purpurascens Poir.	PT	.	.	.	.
	Y1	.	.	0.14	.
	Y2	.	.	0.22	0.14
Axonopus affinis Chase	PT	0.82	0.29	0.03	0.32
	Y1	2.69	3.13	.	.
	Y2	0.92	10.00	.	.
Dichanthelium spp. (Hitchc. & Chase) Gould	PT	13.37	15.69	8.97	19.06
	Y1	24.41	6.04	0.04	0.04
	Y2	20.00	25.01	19.92	26.75
Eragrostis spp. N. M. von Wolf	PT	.	0.01	.	.
	Y1	.	1.18	.	.
	Y2	.	0.42	.	.
Panicum anceps Michx.	PT	.	.	0.89	0.69
	Y1	0.75	.	.	.
	Y2	0.50	1.25	1.00	0.04
Panicum hemitomum Schult.	PT	.	.	.	.
	Y1	.	.	.	.
	Y2	.	0.42	.	.
Paspalum notatum Fluegge	PT	0.03	.	.	.
	Y1	.	0.90	.	.
	Y2	0.49	1.04	1.08	.
Paspalum spp. L.	PT	.	.	.	0.51
	Y1	.	.	.	.
	Y2	.	.	.	.
Paspalum setaceum Michx.	PT	1.58	0.10	0.62	2.03
	Y1	6.85	2.33	1.11	.
	Y2	2.68	7.33	2.83	4.68
Sporobolus junceus (Michx.) Kunth.	PT	.	.	.	.
	Y1	.	.	.	.
	Y2	.	.	.	0.68
FORBS					
Acalypha gracilens A. Gray	PT	.	.	.	.
	Y1	0.11	.	.	.
	Y2	0.07	.	.	.
Ambrosia artemisiifolia L.	PT	0.14	.	.	.
	Y1	.	.	.	.
	Y2	.	.	.	.
Cassia nictitans L.	PT	0.13	0.14	.	0.15
	Y1	8.44	0.69	.	.
	Y2	3.48	8.25	2.58	1.00

APPENDIX--continued.
Mesic Flatwoods.

Species	Time	Hexazinone rate (kg/ha) 0.0	1.7	3.4	6.8
		---- Foliar cover (%) ---			
Centella asiatica (L.) Urban	PT	.	.	.	.
	Y1	.	.	.	.
	Y2	0.10	.	0.13	0.94
Cirsium horridulum Michx.	PT	0.39	.	.	.
	Y1	.	.	.	.
	Y2	.	.	.	.
Crotalaria rotundifolia (Walt.) Gmel.	PT	0.06	.	.	0.11
	Y1	0.54	.	.	.
	Y2	0.04	0.13	.	.
Croton glandulosus L.	PT	.	.	.	.
	Y1	.	.	.	.
	Y2	.	0.28	.	.
Crotonopsis linearis Michx.	PT	.	.	0.13	0.19
	Y1	.	.	.	.
	Y2	.	.	.	0.24
Desmodium spp. Desv.	PT	0.15	.	0.04	.
	Y1	.	.	.	.
	Y2	.	.	.	.
Diodia teres Walt.	PT	0.08	.	0.04	0.25
	Y1	.	.	.	.
	Y2	.	0.50	.	.
Elephantopus elatus Bertol.	PT	.	.	.	.
	Y1	.	.	.	.
	Y2	0.44	.	.	.
Erechtites hieracifolia (L.) Raf.	PT	1.14	.	1.99	1.42
	Y1	.	.	0.14	.
	Y2	.	.	.	.
Eriogonum tomentosum Michx.	PT	.	.	.	.
	Y1	.	.	.	.
	Y2	0.14	.	.	.
Eryngium sp. L.	PT	0.13	.	.	.
	Y1	.	.	.	.
	Y2	.	.	.	.
Eupatorium sp. L.	PT	.	.	.	.
	Y1	.	.	.	.
	Y2	.	0.03	.	.
Eupatorium album L.	PT	.	.	.	.
	Y1	.	.	.	.
	Y2	.	.	0.35	0.23

APPENDIX--continued.
Mesic Flatwoods.

Species	Time	Hexazinone rate (kg/ha) 0.0	1.7	3.4	6.8
		---- Foliar cover (%) ---			
Eupatorium capillifolium (Lam.) Small	PT	0.17	.	.	.
	Y1	1.90	.	.	.
	Y2	1.38	0.54	2.06	6.35
Eupatorium compositifolium Walt.	PT	0.07	0.33	1.57	0.19
	Y1	4.29	.	.	.
	Y2	7.31	2.52	3.46	1.33
Euthamia minor (Michx.) Greene	PT	.	.	.	.
	Y1	0.94	.	.	.
	Y2	5.10	0.21	0.29	0.71
Fimbristylis spp. Vahl.	PT	.	0.47	0.15	0.50
	Y1	.	0.50	0.14	.
	Y2	.	.	0.07	0.68
Froelichia floridana (Nutt.) Moq.	PT	0.03	.	0.11	.
	Y1	.	.	.	.
	Y2	.	.	.	.
Galactia regularis (L.) BSP.	PT	.	.	.	.
	Y1	0.29	.	.	.
	Y2	.	.	.	.
Galium sp. L.	PT	.	.	.	.
	Y1	.	.	.	.
	Y2	0.18	.	.	.
Hedyotis procumbens (J.F. Gmel.) Fosberg	PT	0.15	0.04	.	0.03
	Y1	.	.	.	.
	Y2	0.76	.	.	0.07
Helianthemum carolinianum (Walt.) Michx.	PT	.	.	.	.
	Y1	.	.	.	.
	Y2	.	0.02	.	.
Helianthemum corymbosum Michx.	PT	.	.	.	.
	Y1	0.97	.	.	.
	Y2	1.46	0.20	.	.
Hypericum gentianoides (L.) BSP.	PT	0.35	0.28	0.03	0.14
	Y1	0.73	0.19	.	.
	Y2	.	0.35	0.06	0.17
Lachnocaulon spp. Kunth.	PT	0.50	.	.	0.69
	Y1	.	.	.	.
	Y2	.	.	.	.
Lechea spp. L.	PT	.	.	.	.
	Y1	0.10	.	.	.
	Y2	.	0.04	0.08	.

APPENDIX--continued.
Mesic Flatwoods.

Species	Time	Hexazinone rate (kg/ha) 0.0	1.7	3.4	6.8
		---- Foliar cover (%) ---			
Ludwigia spp. L.	PT	.	.	.	.
	Y1	.	.	0.07	.
	Y2	.	0.10	0.04	.
Phytolacca americana L.	PT	.	.	.	.
	Y1	.	0.10	.	.
	Y2	.	0.50	.	.
Polygala lutea L.	PT	.	.	.	.
	Y1	.	.	.	.
	Y2	.	.	.	0.14
Polypremum procumbens L.	PT	.	.	.	.
	Y1	0.85	0.14	.	.
	Y2	1.58	3.35	5.07	1.64
Pterocaulon virgatum (L.) DC.	PT	.	0.28	.	.
	Y1	.	.	.	.
	Y2	.	0.15	.	.
Rhexia mariana L.	PT	0.49	0.10	0.08	0.13
	Y1	0.96	0.56	0.03	.
	Y2	2.85	2.71	0.60	4.04
Richardia scabra L.	PT	0.06	.	.	.
	Y1	0.68	.	.	.
	Y2	0.99	0.04	1.61	0.83
Scleria spp. Berg.	PT	.	.	.	.
	Y1	.	.	.	.
	Y2	0.86	.	.	.
Scoparia dulcis L.	PT	.	.	.	.
	Y1	.	.	0.14	.
	Y2	.	.	.	.
Solidago spp. L.	PT	0.04	0.24	.	.
	Y1	.	.	.	.
	Y2	.	.	.	.
Tephrosia virginiana (L.) Pers.	PT	.	.	.	.
	Y1	.	.	0.03	.
	Y2	.	.	.	.
Vernonia sp. Schreber	PT	.	.	.	.
	Y1	0.14	.	.	.
	Y2	.	.	.	.
Xyris spp. L.	PT	.	.	.	.
	Y1	.	.	.	.
	Y2	.	.	0.03	0.29

APPENDIX--continued.
Hydric Hammock.

Species	Time	Hexazinone rate (kg/ha) 0.0	1.7	3.4	6.8
		---- Foliar cover (%) ---			
TREES AND SHRUBS					
Acer rubrum L.	PT	0.05	.	0.10	0.04
	Y1	.	0.06	.	.
	Y2	.	.	0.08	.
Acer saccharum Marsh.	PT	.	0.04	.	.
	Y1	.	.	.	.
	Y2	.	.	.	.
Baccharis halimifolia L.	PT	14.53	9.73	9.63	10.73
	Y1	43.17	23.52	8.23	2.25
	Y2	47.23	35.95	20.06	5.70
Betula nigra L.	PT	.	.	.	.
	Y1	.	.	0.04	.
	Y2	.	.	.	.
Bumelia reclinata Vent.	PT	.	.	.	.
	Y1	.	.	0.17	.
	Y2	.	0.04	0.13	0.02
Callicarpa americana L.	PT	.	0.06	.	.
	Y1	.	0.42	.	.
	Y2	.	.	.	.
Carpinus caroliniana Walt.	PT	2.44	2.25	4.38	2.72
	Y1	1.76	0.75	0.10	0.83
	Y2	4.06	1.44	1.73	2.33
Carya aquatica (Michx. f.) Nutt.	PT	.	0.61	.	.
	Y1	.	0.69	.	.
	Y2	.	0.77	.	.
Celtis laevigata Willd.	PT	.	.	0.06	.
	Y1	.	.	.	.
	Y2	.	.	.	.
Cornus foemina Mill.	PT	0.33	0.83	1.12	1.09
	Y1	0.10	0.25	0.21	0.13
	Y2	0.19	0.15	0.13	0.04
Crataegus spp. L.	PT	.	0.15	.	.
	Y1	.	.	.	.
	Y2	.	0.04	.	.
Cyrilla racemiflora L.	PT	.	.	.	.
	Y1	.	0.02	.	.
	Y2	.	.	.	.

APPENDIX--continued.
Hydric Hammock.

Species	Time	Hexazinone rate (kg/ha) 0.0	1.7	3.4	6.8
		---- Foliar cover (%) ---			
Diospyros virginiana L.	PT	0.30	0.73	0.33	1.74
	Y1	0.55	.	.	0.23
	Y2	1.09	1.42	0.08	0.10
Euonymous americanus L.	PT	.	.	.	.
	Y1	.	.	.	.
	Y2	.	0.04	.	.
Forestiera segregata (Jacq.) Krug & Urban	PT	.	.	.	.
	Y1	.	.	.	.
	Y2	.	0.02	.	.
Fraxinus pennsylvanica Marsh.	PT	.	.	.	0.03
	Y1	.	.	.	.
	Y2	.	0.04	.	.
Gaylussacia dumosa (Andr.) Torr. & Gray	PT	.	.	.	.
	Y1	.	0.08	.	.
	Y2	.	.	.	.
Hypericum spp. L.	PT	0.47	0.33	0.48	0.83
	Y1	0.67	1.00	0.38	.
	Y2	0.47	1.40	1.00	0.23
Ilex vomitoria Ait.	PT	0.43	1.21	0.64	0.49
	Y1	0.29	3.29	0.56	0.94
	Y2	0.10	4.29	1.31	1.71
Leucothoe racemosa (L.) A. Gray	PT	.	.	.	.
	Y1	.	.	.	.
	Y2	.	0.04	.	.
Liquidambar styraciflua L.	PT	8.71	6.29	7.39	11.09
	Y1	15.93	5.08	1.65	0.52
	Y2	23.23	7.69	1.83	0.23
Magnolia grandiflora L.	PT	.	.	.	.
	Y1	.	.	.	.
	Y2	.	.	0.08	.
Magnolia virginica L.	PT	0.22	.	0.25	.
	Y1	0.94	.	0.17	.
	Y2	1.06	.	0.21	.
Myrica cerifera L.	PT	0.10	.	0.86	.
	Y1	0.08	0.13	0.17	.
	Y2	0.29	0.73	0.27	.
Ostrya virginiana (Mill.) K. Koch	PT	0.07	0.20	.	.
	Y1	0.10	0.10	.	.
	Y2	.	.	.	.

APPENDIX--continued.
Hydric Hammock.

Species	Time	Hexazinone rate (kg/ha) 0.0	1.7	3.4	6.8
		---- Foliar cover (%) ---			
Persia borbonia (L.) Spreng.	PT	0.24	0.39	0.79	0.56
	Y1	0.56	0.50	0.19	.
	Y2	1.37	1.95	0.81	0.33
Pinus taeda L.	PT	.	.	.	0.08
	Y1	.	.	.	0.73
	Y2	0.08	0.27	.	2.75
Prunus americana Marsh.	PT	.	.	.	0.18
	Y1	.	.	.	.
	Y2	.	.	.	.
Quercus laurifolia Michx.	PT	4.29	2.49	0.90	1.46
	Y1	3.06	1.58	0.13	0.21
	Y2	2.89	1.44	0.23	0.06
Quercus michauxii Nutt.	PT	0.05	.	.	.
	Y1	.	.	.	.
	Y2	.	.	.	.
Quercus nigra L.	PT	0.33	0.58	0.96	0.05
	Y1	0.23	0.63	0.46	0.04
	Y2	0.40	0.54	0.46	.
Quercus shummardii Buckl.	PT	.	0.09	.	.
	Y1	0.23	.	0.38	0.04
	Y2	.	.	.	.
Quercus virginiana Mill.	PT	0.33	0.94	.	.
	Y1	0.33	0.29	.	.
	Y2	1.02	0.25	.	.
Sabal palmetto (Walt.) Lodd. ex Schultes	PT	3.85	1.22	1.94	1.45
	Y1	6.22	2.54	1.94	1.67
	Y2	6.49	2.10	2.27	1.83
Ulmus alata Michx.	PT	.	0.17	0.13	0.11
	Y1	.	.	.	.
	Y2	0.04	.	.	.
Ulmus crassifolia Nutt.	PT	.	.	.	.
	Y1	.	.	.	.
	Y2	0.29	0.02	.	0.02
Viburnum dentatum L.	PT	.	.	.	.
	Y1	.	0.04	.	.
	Y2	.	0.21	.	.
Viburnum obovatum Walt.	PT	.	.	.	0.26
	Y1	0.02	0.08	0.06	0.08
	Y2	0.42	0.06	0.04	0.21

APPENDIX--continued.
Hydric Hammock.

Species	Time	Hexazinone rate (kg/ha) 0.0	1.7	3.4	6.8
		---- Foliar cover (%) ---			
Viburnum rufidulum Raf.	PT	.	.	.	.
	Y1	.	.	.	.
	Y2	.	0.31	.	.
WOODY VINES					
Ampelopsis arborea (L.) Koehne	PT	.	.	.	0.13
	Y1	.	0.07	.	.
	Y2	0.19	.	.	.
Berchemia scandens (Hill) K. Koch	PT	0.12	0.05	0.90	0.05
	Y1	0.02	0.06	0.42	0.04
	Y2	0.10	0.06	0.38	0.13
Bignonia capreolata L.	PT	0.44	0.59	0.28	0.09
	Y1	0.65	0.23	0.10	0.19
	Y2	0.07	0.15	.	.
Decumaria barbara L.	PT	.	.	.	.
	Y1	.	.	.	.
	Y2	.	.	0.29	.
Gelsemium sempervirens (L.) J. St. Hil.	PT	.	0.03	0.04	.
	Y1	.	.	.	.
	Y2	.	0.02	.	.
Lonicera sempervirens L.	PT	.	0.08	.	.
	Y1	.	.	.	.
	Y2	.	.	.	.
Parthenocissus quinquefolia (L.) Planch.	PT	0.10	0.05	0.06	.
	Y1	.	.	.	.
	Y2	0.19	0.08	.	0.02
Rubus betulifolius Small	PT	0.72	0.10	2.70	1.90
	Y1	0.58	0.33	.	.
	Y2	0.68	0.40	0.21	0.25
Rubus trivialis Michx.	PT	0.48	0.08	0.72	2.00
	Y1	1.20	0.13	0.50	0.04
	Y2	0.78	0.10	.	0.63
Smilax auriculata Walt.	PT	0.06	.	.	.
	Y1	.	.	.	.
	Y2	.	.	0.08	.
Smilax bona-nox L.	PT	2.94	1.62	3.23	1.89
	Y1	3.33	2.73	2.03	0.96
	Y2	1.53	1.21	1.06	0.92
Smilax tamnoides L.	PT	0.68	1.54	0.45	0.68
	Y1	1.41	0.06	0.13	0.15
	Y2	0.34	0.29	.	0.08

APPENDIX--continued.
Hydric Hammock.

Species	Time	Hexazinone rate (kg/ha) 0.0	1.7	3.4	6.8
		---- Foliar cover (%) ---			
Toxicodendron radicans (L.) Kuntze.	PT	0.53	0.80	0.83	0.11
	Y1	0.28	0.17	0.50	0.06
	Y2	0.44	0.13	0.10	0.13
Trachelospermum difforme (Walt.) A. Gray	PT	.	.	.	.
	Y1	.	.	.	.
	Y2	.	0.13	.	.
Vitis aestivalis Michx.	PT	8.30	2.51	8.16	1.47
	Y1	6.61	0.79	0.19	.
	Y2	7.99	2.52	0.69	0.17
Vitis rotundifolia Michx.	PT	3.32	1.85	7.16	0.66
	Y1	5.52	0.83	0.27	.
	Y2	7.02	1.50	1.21	0.04
Vitis vulpina L.	PT	0.22	.	.	.
	Y1	0.44	.	.	.
	Y2	0.49	.	.	0.02
GRASS-LIKES					
Carex spp. L.	PT	59.12	35.94	41.26	48.22
	Y1	34.58	28.48	16.37	8.97
	Y2	20.95	22.43	15.28	18.24
Cyperus spp. L.	PT	0.19	0.14	.	0.10
	Y1	.	0.54	.	0.28
	Y2	.	1.42	0.07	3.56
Dichromena colorata (L.) Hitchc.	PT	.	.	.	1.07
	Y1	.	.	.	.
	Y2	.	.	.	0.14
Juncus spp. L.	PT	.	1.40	0.99	0.14
	Y1	.	0.31	.	.
	Y2	.	1.53	0.26	0.14
Rhynchospora spp. Vahl	PT	12.26	15.75	8.76	20.67
	Y1	28.31	6.75	6.40	4.80
	Y2	18.97	7.45	14.26	17.64
GRASSES					
Andropogon spp. L.	PT	.	0.38	.	.
	Y1	.	.	.	.
	Y2	.	.	.	.
Andropogon capillipes Nash	PT	.	.	.	.
	Y1	.	.	.	.
	Y2	.	0.46	.	.

APPENDIX--continued.
Hydric Hammock.

Species	Time	Hexazinone rate (kg/ha) 0.0	1.7	3.4	6.8
		---- Foliar cover (%) ---			
Andropogon glomeratus (Walt.) BSP.	PT	7.85	6.19	5.57	1.88
	Y1	11.50	7.32	6.95	3.61
	Y2	7.01	21.81	19.31	17.93
Andropogon virginicus L.	PT	.	.	.	0.64
	Y1	.	1.10	.	2.01
	Y2	.	0.07	.	.
Chasmanthium laxum (L.) Yates	PT	12.10	3.78	18.20	17.86
	Y1	2.86	.	0.58	0.06
	Y2	8.57	5.26	8.82	1.60
Dichanthelium commutatum (Schult.) Gould	PT	11.68	18.90	18.23	6.18
	Y1	7.44	8.26	11.37	4.89
	Y2	3.87	10.50	8.99	9.88
Dichanthelium dichotomum (L.) Gould	PT	.	.	.	.
	Y1	.	.	.	.
	Y2	0.14	0.61	1.64	0.42
Leersia hexandra Sw.	PT	1.38	1.96	3.27	1.67
	Y1	.	0.14	0.74	0.04
	Y2	1.54	2.63	3.24	1.88
Oplismenus setarius (Lam.) Roem. & Schult.	PT	.	.	.	.
	Y1	.	0.22	2.37	.
	Y2	1.38	0.22	1.83	.
Panicum adspermum Trin.	PT	.	.	.	.
	Y1	.	.	.	.
	Y2	.	0.42	.	.
Panicum anceps Michx.	PT	.	.	.	.
	Y1	0.14	1.29	0.69	.
	Y2	.	.	.	.
Panicum rigidulum Nees.	PT	1.16	1.92	1.90	0.72
	Y1	2.50	4.06	0.83	0.21
	Y2	0.49	5.60	0.67	2.04
Paspalum spp. L.	PT	.	.	.	.
	Y1	.	0.24	.	0.03
	Y2	.	.	.	.
FORBS					
Asclepia perennis Walt.	PT	.	.	0.13	0.11
	Y1	.	.	.	.
	Y2	.	.	.	.
Aster sp. L.	PT	0.17	.	.	.
	Y1	0.14	.	.	.
	Y2	.	.	.	.

APPENDIX--continued.
Hydric Hammock.

Species	Time	Hexazinone rate (kg/ha) 0.0	1.7	3.4	6.8
		---- Foliar cover (%) ---			
Centella asiatica (L.) Urban	PT	.	1.64	0.25	.
	Y1	0.07	0.80	.	.
	Y2	.	0.35	.	.
Cirsium horridulum Michx.	PT	.	0.31	.	.
	Y1	.	.	.	.
	Y2	.	.	.	.
Conoclinium colestinum (L.) DC.	PT	.	.	2.10	0.93
	Y1	.	.	.	.
	Y2	.	.	.	0.60
Elephantopus nudatus A. Gray	PT	.	.	0.28	.
	Y1	.	0.08	0.81	.
	Y2	.	0.21	.	.
Elytraria caroliniensis (J.F. Gmel.) Pers.	PT	1.08	0.83	0.81	0.95
	Y1	0.36	0.21	0.76	1.08
	Y2	.	0.65	0.81	0.49
Erechtites hieracifolia (L.) Raf.	PT	3.68	1.83	4.18	0.96
	Y1	.	.	0.43	.
	Y2	0.15	0.35	1.47	0.95
Eupatorium capillifolium (Lam.) Small	PT	9.47	8.98	8.48	8.21
	Y1	37.23	4.29	.	.
	Y2	1.18	1.79	9.92	23.12
Eupatorium compositifolium Walt.	PT	.	.	0.04	.
	Y1	.	.	.	.
	Y2	.	0.13	.	.
Eupatorium perfoliatum L.	PT	0.18	0.36	.	0.86
	Y1	0.28	1.68	0.49	0.13
	Y2	.	0.83	.	0.78
Galium sp. L.	PT	.	.	.	.
	Y1	.	.	.	.
	Y2	.	0.06	.	.
Hedyotis uniflora (L.) Lam.	PT	0.30	0.08	0.31	0.42
	Y1	0.28	3.42	.	.
	Y2	0.63	4.82	1.88	1.26
Hibiscus coccineus Walt.	PT	.	.	.	.
	Y1	.	0.15	.	.
	Y2	.	.	.	.
Hydrocotyl umbellata L.	PT	0.14	0.15	.	0.07
	Y1	0.14	0.04	.	.
	Y2	0.57	0.21	1.74	1.99

APPENDIX--continued.
Hydric Hammock.

Species	Time	Hexazinone rate (kg/ha) 0.0	1.7	3.4	6.8
		---- Foliar cover (%) ---			
Hyptis alata (Raf.) Shinners	PT	.	.	.	.
	Y1	.	.	.	.
	Y2	.	.	.	1.89
Justicia angusta (Chapm.) Small	PT	.	.	.	.
	Y1	.	.	0.39	.
	Y2	.	.	.	.
Lippia nodiflora (L.) Michx.	PT	0.78	1.14	.	.
	Y1	1.28	0.19	.	.
	Y2	1.02	0.72	.	.
Ludwigia microcarpa Michx.	PT	0.07	4.01	.	.
	Y1	.	1.64	.	0.15
	Y2	1.79	1.47	1.95	5.50
Matelea suberosa (L.) Shinners	PT	.	0.05	.	.
	Y1	.	0.35	.	.
	Y2	.	.	0.17	.
Mikania scandens (L.) Willd.	PT	0.89	1.02	0.71	0.41
	Y1	1.17	1.29	1.31	.
	Y2	0.49	1.17	6.35	4.74
Mitreola petiolata (J.F. Gmel.) Torr. & Gray	PT	0.70	0.26	0.25	0.21
	Y1	.	.	.	.
	Y2	0.61	1.63	0.64	2.53
Oxalis sp. L.	PT	.	.	.	.
	Y1	.	.	.	.
	Y2	.	.	.	0.82
Passiflora sp. L.	PT	0.05	.	.	.
	Y1	.	.	.	.
	Y2	.	.	.	.
Phytolacca americana L.	PT	.	.	.	.
	Y1	.	.	.	.
	Y2	.	.	.	0.88
Pluchea longifolia Nash	PT	.	.	.	0.21
	Y1	.	.	.	.
	Y2	0.37	0.35	.	.
Polygonum hydropiperoides Michx.	PT	0.46	3.71	0.14	.
	Y1	0.69	1.68	.	.
	Y2	0.44	1.86	1.71	2.42
Ruellia caroliniensis (J.F. Gmel.) Steud.	PT	0.14	0.25	.	0.21
	Y1	0.82	0.33	0.82	0.07
	Y2	0.82	1.53	3.42	0.44

APPENDIX--continued.
Hydric Hammock.

Species	Time	Hexazinone rate (kg/ha) 0.0	1.7	3.4	6.8
		---- Foliar cover (%) ---			
Scutellaria integrifolia L.	PT	.	0.10	.	.
	Y1	.	.	.	.
	Y2	.	.	0.11	0.07
Solidago sp. L.	PT	.	.	.	.
	Y1	.	.	.	.
	Y2	.	.	.	0.13
Spilanthes americana (Mutis ex L.f.) Hieron	PT	.	.	.	1.50
	Y1	0.56	0.22	.	0.07
	Y2	.	.	.	.
Stillingia sylvatica L.	PT	.	.	.	.
	Y1	.	.	0.14	.
	Y2	.	.	.	.
Teucrium canadense L.	PT	0.69	.	0.29	0.20
	Y1	0.44	.	.	.
	Y2	0.89	.	.	.
Trepocarpus aethusae Nutt.	PT	.	1.17	.	.
	Y1	0.07	.	.	.
	Y2	.	.	.	.
Trichostema dichotomum L.	PT	.	.	.	.
	Y1	.	.	0.07	0.06
	Y2	.	0.07	.	.
Vernonia sp. Schreber	PT	.	.	.	.
	Y1	.	.	.	.
	Y2	.	.	.	0.69
Viola affinis LeConte	PT	0.45	0.69	0.71	0.07
	Y1	0.15	0.21	0.82	0.15
	Y2	0.04	.	0.10	0.22
Viola lanceolata L.	PT	.	.	.	.
	Y1	.	.	.	.
	Y2	.	0.18	.	0.60

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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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